BASELINE RISK ASSESSMENT

RUSTON/NORTH TACOMA OPERABLE UNIT
COMMENCEMENT BAY NEARSHORE/TIDEFLATS
SUPERFUND SITE
TACOMA, WASHINGTON

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APPENDIX E

EVALUATION OF GARDEN VEGETABLE UPTAKE FACTORS

One of the pathways by which residents of the Ruston/North Tacoma study area may be exposed to arsenic is ingestion of vegetables grown in arsenic-contaminated soil. This appendix addresses the uptake by garden vegetables of arsenic and other inorganic constituents from contaminated soils. Uptake has been shown in many other studies to depend on the chemical and type of vegetable involved, as well as numerous other factors. In general, predictive models to account for all of the possible influences on chemical uptake are lacking, even though a large literature exists on the topic of plant uptake.

In this appendix, site-specific data sets providing information on garden vegetable and soil concentrations of arsenic and other metals are described and evaluated. This evaluation considers the effects of several factors on plant uptake, including soil pH, type of vegetable, soil concentration, and ambient air arsenic levels. The data from the most extensive local study of garden vegetables are assessed in detail to understand the relationship of vegetable arsenic concentrations in relation to soil levels (uptake factors). The results are compared to those from other available studies. The results of the assessment of uptake factors are used to develop garden vegetable RME arsenic concentrations for the estimation of possible arsenic exposures in the risk assessment. Additional vegetable arsenic concentrations are estimated and used in the risk assessment to characterize the variability in vegetable consumption exposures by location within the study area.

An attachment to this appendix provides details for the selection of garden vegetable contact rates used in the vegetable ingestion exposure model (see Section 4.4 and Appendices G and H), including total dietary intakes and the diet fractions of vegetables (by type) that are home-grown. Estimated uptake rates for contaminants other than arsenic are used in the screening evaluation for contaminants of concern (see Appendix A). Information on lead uptake is also considered in evaluating potential exposure pathways for lead at the Ruston/North Tacoma site (see Section 4.5).

1.0 DATA SETS FOR UPTAKE FACTOR DETERMINATION

1.1 SITE-SPECIFIC GARDEN VEGETABLE AND SOIL STUDIES

Garden vegetable tissue concentrations in relation to soil concentrations of arsenic have been studied in three Ruston and Tacoma area investigations. These investigations are discussed below.

Ratsch (1974) collected 32 matched samples of garden soils (0-2 inches, spot sample) and vegetables in 1973. These samples represent 26 locations, including Vashon Island and a control site in Seattle. Most of the samples were located along two transects from the smelter in Ruston and Tacoma. All samples were analyzed for arsenic, cadmium, lead, and mercury. Both washed and unwashed samples were analyzed. Samples of other tissues (i.e., grass and leaves) were also collected and analyzed.

Heilman and Ekuan (1977) sampled 71 locations in 1974. Sites sampled included Ruston and north Tacoma; Vashon Island; and control sites in Puyallup, Seattle, and Orcas Island. Garden soils were represented by a composite sample (0-6 inches), and a total of 228 garden vegetable samples of 14 different types were collected. The most numerous sample types were lettuce (59 samples), beets (46), beet greens (45), cabbage (38), chard (13), and carrots (10). For all other vegetable types, three or fewer samples were collected. This study represents the most detailed site investigation of garden vegetables to date. Samples were analyzed for arsenic, cadmium, copper, lead, mercury, zinc, and occasionally antimony. All vegetable samples were washed prior to analysis. Heilman and Ekuan (1977) also performed a greenhouse experiment, growing vegetables in soils taken from the site and in control soils from Puyallup.

A third garden vegetable investigation was performed for the Tacoma-Pierce County and Seattle-King County Health Departments. The study report (Lowry 1983) addresses only the garden soil sampling results (0-6 inches, composite). Laboratory data for the vegetable tissue sample results, however, were available for review for this risk assessment. Sampling sites were located in Ruston, north Tacoma, Vashon Island, Gig Harbor, Browns Point, south Tacoma, and Puyallup. All 129 vegetable samples, whether washed or unwashed, were analyzed for arsenic and cadmium. The type of vegetable was specifically identified (e.g., lettuce or carrots) for some of the samples, but others were simply noted as leafy or root vegetables.

Among the three available studies of garden vegetables in the Ruston/Tacoma area, the overall ranges of soil arsenic are similar, although the distributions of values within those ranges differ. The observed ranges for soil arsenic concentrations are as follows: 7 to 457 mg/kg (Ratsch 1974), 5 to 470 mg/kg (Heilman and Ekuan 1977), and 1 to 332 mg/kg (Lowry 1983). According to recent soil sampling studies (see Appendix C), a little more than 10 percent of surface soil arsenic concentrations in the currently defined study area may exceed the highest values included in these garden vegetable studies. Normal gardening practices and the use of soil amendments may decrease arsenic concentrations in garden soils in comparison with those in relatively undisturbed yard soils.

Minor additional information on garden vegetables exists apart from the three studies discussed above. As part of the Exposure Pathways Study (Pathways Study) (Polissar et al. 1987), 21 garden vegetable samples were collected and analyzed for arsenic. However, these limited data did not contribute significantly to the exposure pathways analyses in that study and are not considered further here.

Some additional information on garden soil and vegetable arsenic concentrations (sample collection about 1973-1983) is contained in Asarco files made available to the Pathways Study team and EPA (Asarco 1985). Data for various sites in Ruston and north Tacoma are included, with analyses for arsenic and various other constituents.

No study of arsenic concentrations in garden vegetables has been performed since shutdown of the smelter in 1985-1986. Therefore, there is no way to determine whether these earlier studies, which were performed during the period of smelter operations, are representative of current conditions in the study area. Issues related to the representativeness of pre-1986 data are discussed as part of the data evaluations below. The data evaluations focus on the Heilman and Ekuan (1977) data set from 1974, although the other two major data sets (Ratsch 1974, and Lowry 1983) are also reviewed.

1.2 SITE-SPECIFIC STUDIES ON SOIL PH

Acidification effects have been discussed in the literature (see, for example, Malmer 1976) and may occur in soils in various degrees, depending on soil composition, available buffering capacity, and similar characteristics. Gardening practices typically alter native soils and thereby affect the potential for acidification impacts. For example, garden soils are commonly limed to adjust soil pH for more favorable growing conditions. Soil pH affects the mobility of contaminants and the degree to which they are taken up into plants. Soil pH was measured during the Heilman and Ekuan (1977) study and again by Bechtel (1992a) as part of the current RI/FS. Concerns have been raised that studies of garden vegetables grown before plant shutdown may not be representative of current conditions because SO_x emissions from the smelter may have acidified soils, and those possible acidification effects are no longer occurring (ETI 1989).

The Heilman and Ekuan (1977) data for garden soils and vegetables include garden soil pH for composite samples. The Bechtel (1992a) soil sampling for the current RI/FS also includes pH analyses for a subset of surface and subsurface soil samples. These two data sets therefore allow a comparison of pre- and post-shutdown soil pH levels in the study area. This comparison is also possible for garden versus nongarden soils. Distances from the smelter associated with sampling locations are also known for both data sets. Distance is expected to be a suitable surrogate measure for possible acidification (SO_x deposition) effects; therefore, evaluation of pH versus distance relationships is useful. It is noted that Heilman and Ekuan (1977) comment that stepwise regression procedures did not reveal significant pH relationships with vegetable tissue concentrations.

2.0 DATA EVALUATIONS

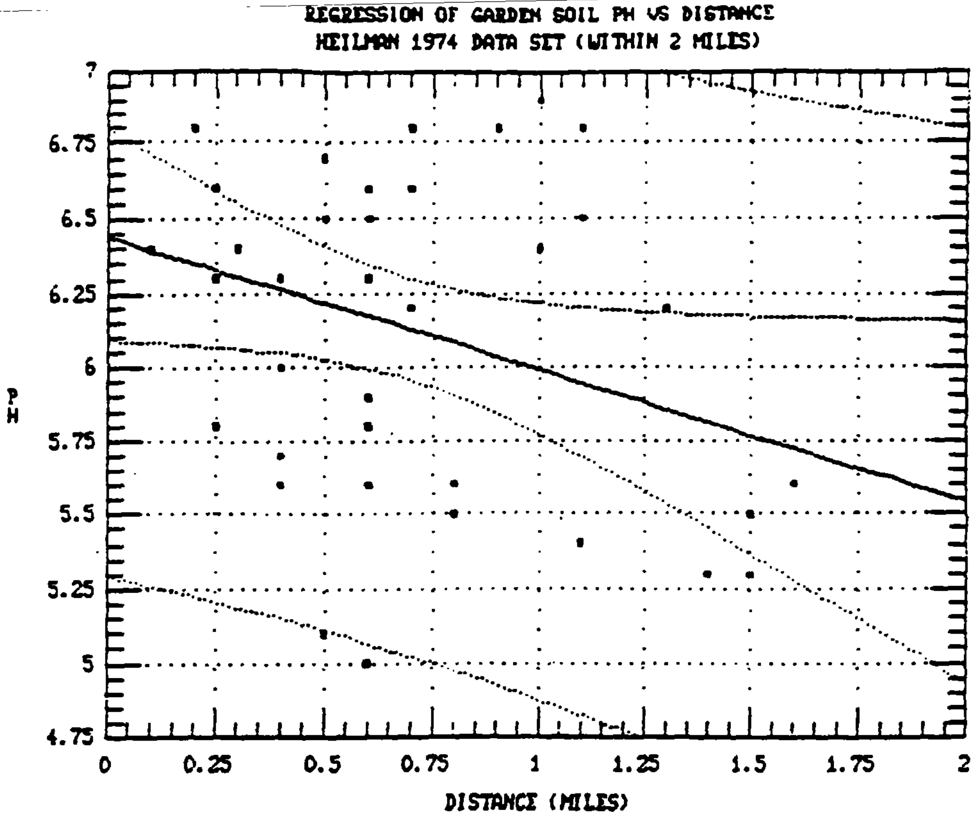
2.1 SOIL PH DATA

The soil sampling conducted in 1990 by Bechtel (1992a) resulted in 56 pH data points. Four types of samples were collected:

- Surface soil (n=11), average pH=5.74
- Soil from depth of 6 inches (n=8), average pH=5.92
- Soil from depth of 12 inches (n=8), average pH=5.98
- Non-residential surface soil and sediment samples (see Bechtel 1992a) (n=20), average pH=6.06

The garden soils collected in 1974 from 70 of the 71 sampled locations, including locations beyond the boundary of the current study area, were analyzed for pH by Heilman and Ekuan (1977). The overall average pH for these 70 samples was 6.06. The 41 samples within 2 miles of the smelter had an average pH of 6.13; 23 samples between 2 and 10 miles from the smelter averaged 5.87. Six control sites at a distance greater than 10 miles averaged 6.27.

For soils within 2 miles of the smelter, pH versus distance is shown in Figure E-1 for Bechtel surface soils (surface and nonresidential surface soil and sediment sample locations) and Heilman and Ekuan (1977) 1974 garden soils. The pH range is about the same in both studies. Regression lines for both data sets are also provided in Figure E-1. For garden soils in 1974, pH decreased with distance, although with considerable scatter ($p=0.05$). On the contrary, for surface soils collected in 1990 (Bechtel 1992a) more than 4 years after smelter shutdown, pH increased with distance ($p=0.02$). The two regression lines cross at a distance of 0.75 to 1.0 miles from the smelter. The average pH of garden soil close to the smelter in 1974 was higher than that of current yard soils in the same area. The Bechtel regression result is consistent with



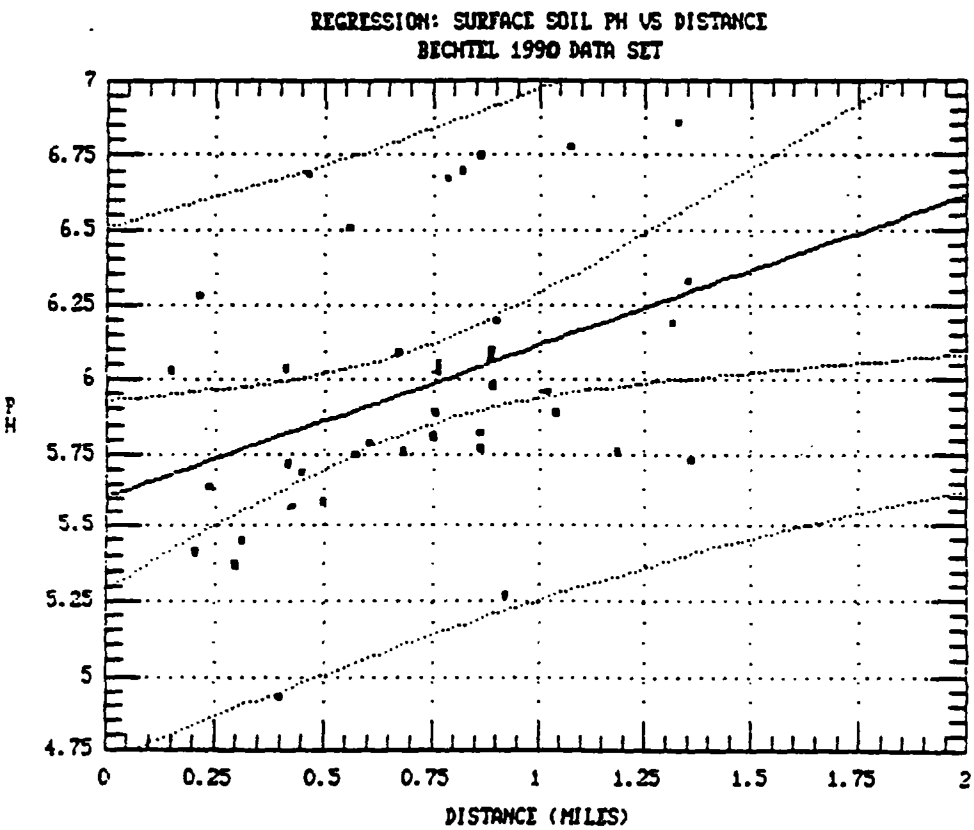


FIGURE E-1

SOIL pH VERSUS DISTANCE FROM SMELTER HEILMAN (1974) AND BECHTEL (1990) DATA

the presence of some residual soil acidification near the smelter, although it may also be a sampling artifact or result from entirely unrelated causes.

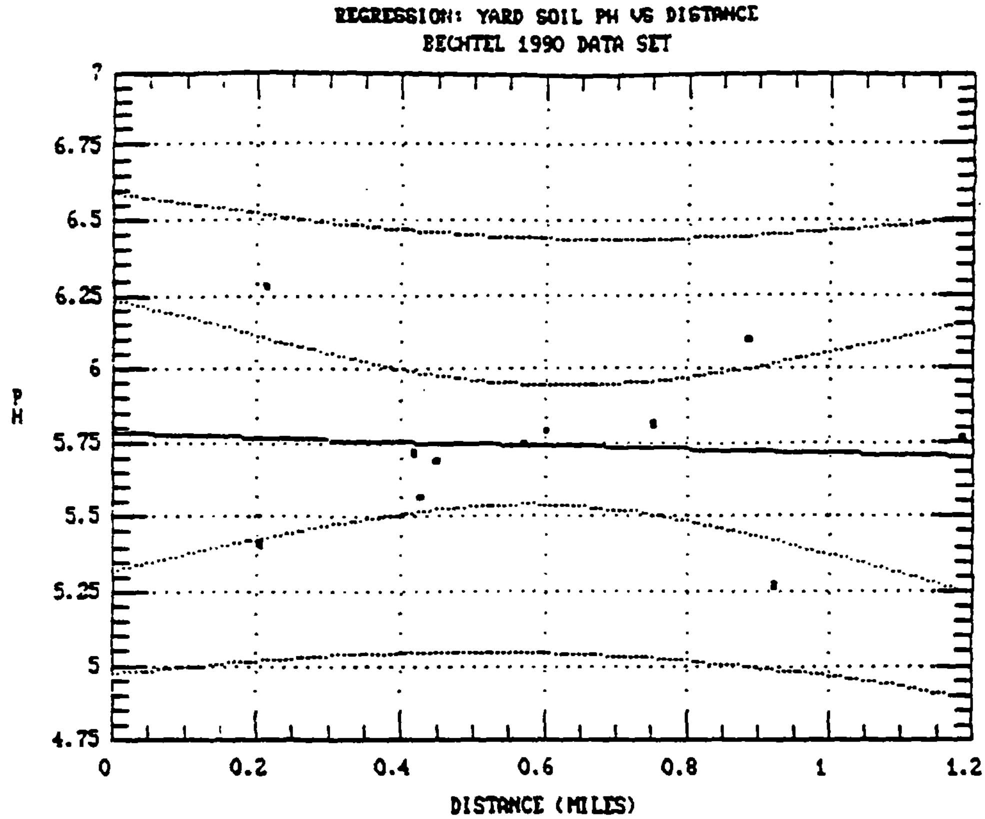
The pH data for Bechtel (1992a) residential yard surface samples (excluding nonresidential surface soil and sediment sampling locations) and Heilman and Ekuan (1977) garden soils within a matched area (less than 1.2 miles from the smelter) are compared in Figure E-2. The trend with distance for Bechtel yard samples is essentially flat, indicating that it is the nonresidential surface soil and sediment sampling locations that determine a trend of pH increasing with distance. This is shown in Figure E-3. The nonresidential surface soil and sediment sampling locations may be less likely than lawn or residential yard areas to be affected by human activities. The trend for garden soil pH within 1.2 miles of the smelter in 1974 is also essentially flat, at about 0.5 pH units higher than current yard soils from Bechtel data. The scatter of pH values around the overall average of about 6.25 probably reflects variation in gardening practices and soil amendments rather than any direct effects of acidification.

2.2 GARDEN VEGETABLE UPTAKE DATA

2.2.1 Heilman and Ekuan Study (1977)

The Heilman and Ekuan data for this site represent one of the largest known studies of the relationship of plant uptake and soil contaminant concentrations for any site. A detailed evaluation of the Heilman and Ekuan garden vegetable data from 1974 was performed. Tissue concentrations for each of the 228 garden vegetable samples and for each of the six major constituents analyzed were compared to average soil concentrations. The data for both tissue and soil concentrations were expressed as dry weight values. The ratio of tissue to soil dry weight concentrations represents an uptake factor for that sample (the value that when multiplied by the soil concentration equals the vegetable tissue concentration. Data from EPA laboratory analyses were used in the data evaluation (see Heilman and Ekuan (1977) for a discussion of interlaboratory comparisons).

All of the calculated uptake factors for a specific vegetable type (e.g., lettuce) and single constituent (e.g., arsenic) were then grouped. These data reflect the distribution of uptake factors for the data set across sampling locations, for a single laboratory, vegetable species, and constituent. The basic unit for further analysis of the 1974 data is the set of calculated uptake factors for a single vegetable type and chemical element. The six vegetable types for which data were most numerous (i.e., lettuce, beets, beet greens, cabbage, chard, and carrots) were all assessed, as well as arsenic and the other five metals analyzed (for a total of 36 data evaluations).



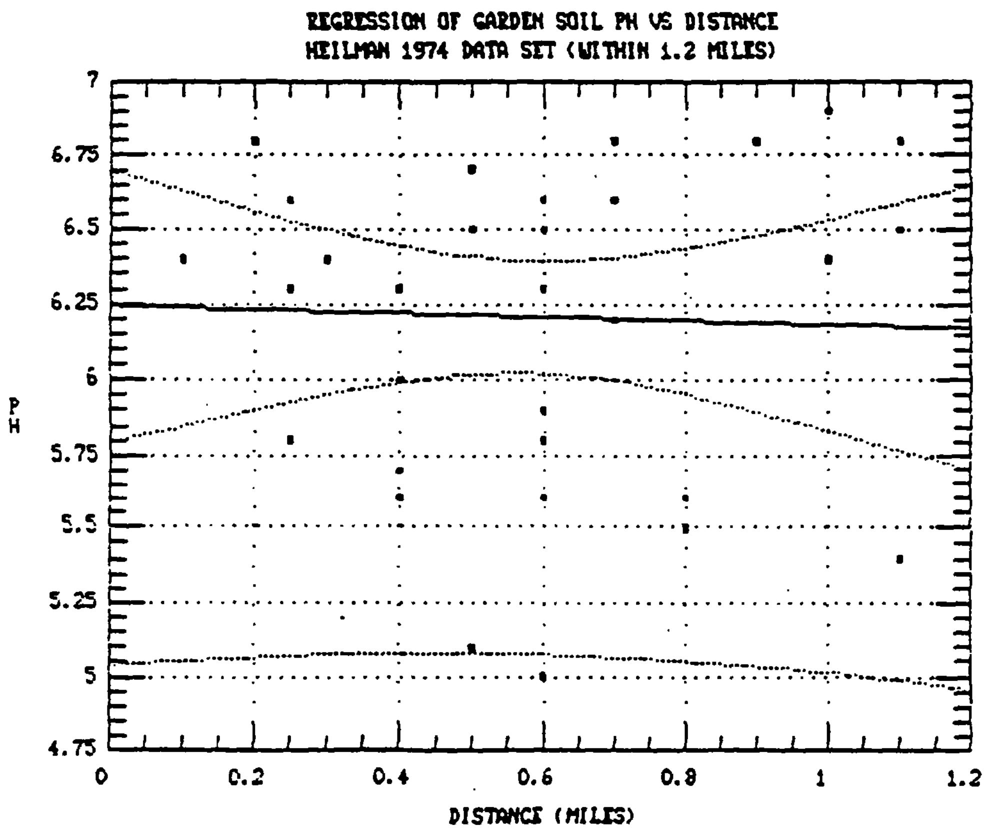


FIGURE E-2

**SOIL pH VERSUS DISTANCE FROM SMELTER
HEILMAN GARDEN (1974) AND BECHTEL YARD (1990) DATA**

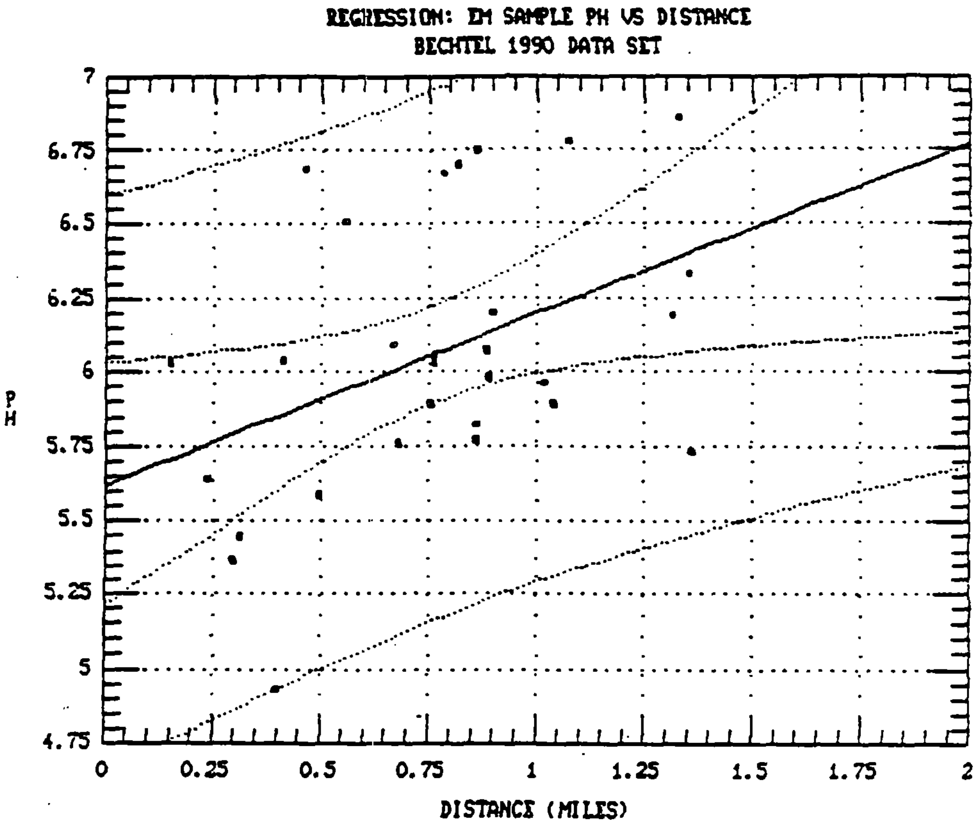


FIGURE E-3

**SOIL pH VERSUS DISTANCE FROM SMELTER
BECHTEL ENVIRONMENTAL MOVEMENT SAMPLES (1990)**

The EPA (1989a) risk assessment guidance document cites a standard reference for development of vegetable uptake factors. According to that reference (Baes et al. 1984), uptake factors for many elements vary significantly as a function of soil concentrations, and a log-log regression plot is the best representation of the relationship between vegetable tissue and soil concentrations. Accordingly, regression analyses of calculated uptake factors versus soil concentrations for the Heilman and Ekuan (1977) data set were incorporated into the data evaluations.

Distributional statistics are not used as the primary data evaluation approach. This decision was made for several reasons. Distributional statistics (e.g., mean and median values) for the sets of uptake factors by element and vegetable type do not reflect the relationship of uptake factors to soil concentrations and are subject to sampling bias effects (not all soil concentrations are equally represented in the data sets). Average uptake factors would also not be representative of most soil concentrations if uptake factors actually varied systematically with soil concentrations. Use of a constant uptake factor would lead to poor estimates of vegetable tissue concentrations and human exposures.

A linear regression line on a log-log plot of the available site-specific data represents a model in which uptake factors are a power function of the soil concentrations. Log-log regression equations have the following general form:

$$\log \text{Uptake Factor} = \text{intercept} + \text{slope} * (\log \text{Soil Concentration})$$

or, using natural logarithms (base e),

$$\text{Uptake Factor} = e^{\text{intercept}} * \text{Soil}^{\text{slope}}$$

$$= (\text{constant}) * \text{Soil}^{\text{slope}}$$

Vegetable tissue concentrations are equal to soil concentrations times the uptake factor. Tissue concentrations therefore vary as a power function of soils where the soil exponent is equal to 1 plus the regression line slope. As a result, the following relationships hold:

- When the slope is -1, tissue concentrations are constant across all soil concentrations.
- When the slope is 0, tissue concentrations vary proportionally with soil concentrations (i.e., the uptake factor is a constant over all soil concentrations).

- When the slope is greater than 0, tissue concentrations increase faster than soil concentrations (i.e., uptake factors increase with increasing soil concentrations).

- When the slope is between -1 and 0, tissue concentrations increase slower than soil concentrations (i.e., uptake factors decrease with increasing soil concentration but not at a rate fast enough to result in constant tissue concentrations).

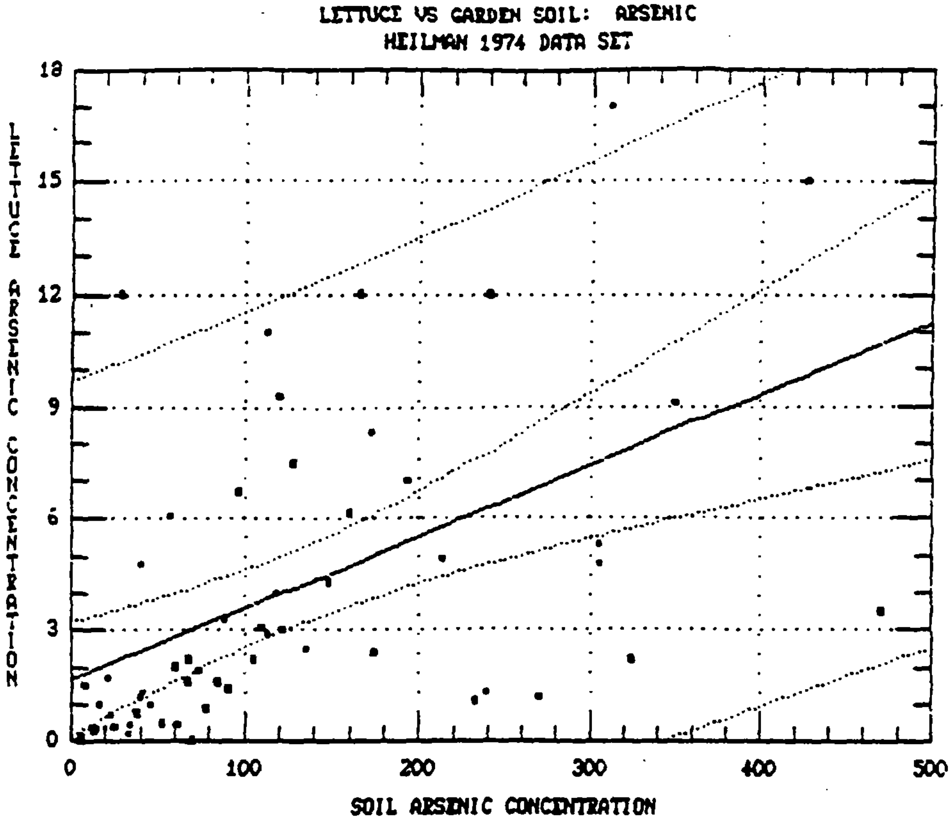
- When the slope is less than -1, tissue concentrations decrease with increasing soil concentrations (a counterintuitive result).

Understanding these relationships may help in interpreting the results of the regression analyses of the Heilman and Ekuan (1977) data.

Examples of vegetable versus soil concentration plots and uptake factor versus soil concentration plots, both with their associated regression lines shown, are provided in Figures E-4 through E-11. Data for arsenic and selected garden vegetables are shown in Figures E-4 and E-5. There is relatively large scatter in the data for arsenic (especially compared to some other metals analyzed). The tissue concentrations of arsenic in lettuce, cabbage, and beets all tended to increase with increases in soil arsenic concentrations, but at a slower rate. Although the data set for carrots is small, the regression line for this vegetable is almost flat (see Figure E-4).

The slope of the regression line for tissue versus soil concentrations, representing change in tissue arsenic concentration per unit of change in soil arsenic, is an estimate of an uptake factor if it is assumed that uptake factor is constant over all soil concentrations. The log-log regression model used here evaluates an alternate nonlinear best fit line for the data, a power function curve. Log-log plots of uptake factors (rather than tissue concentrations) versus soil arsenic concentrations for lettuce and beets are shown in Figure E-5 (same data as shown in comparable Figure E-4 plots, but expressed differently). The regression line for lettuce is almost flat (i.e., uptake factors scattered around a constant value), while the uptake factors for beets show a decided trend downward with increasing soil concentrations.

Similar tissue versus soil and (log-log) uptake factor versus soil plots for lettuce and beet results are provided for cadmium (Figures E-6 and E-7), copper (Figures E-8 and E-9), and mercury (Figures E-10 and E-11). For all of the cases shown, the uptake factors are nonconstant — they decrease as soil concentrations increase. The copper and mercury results for uptake factor versus soil plots (Figures E-9 and E-11) illustrate the very strong fit of the data to the model in many cases.



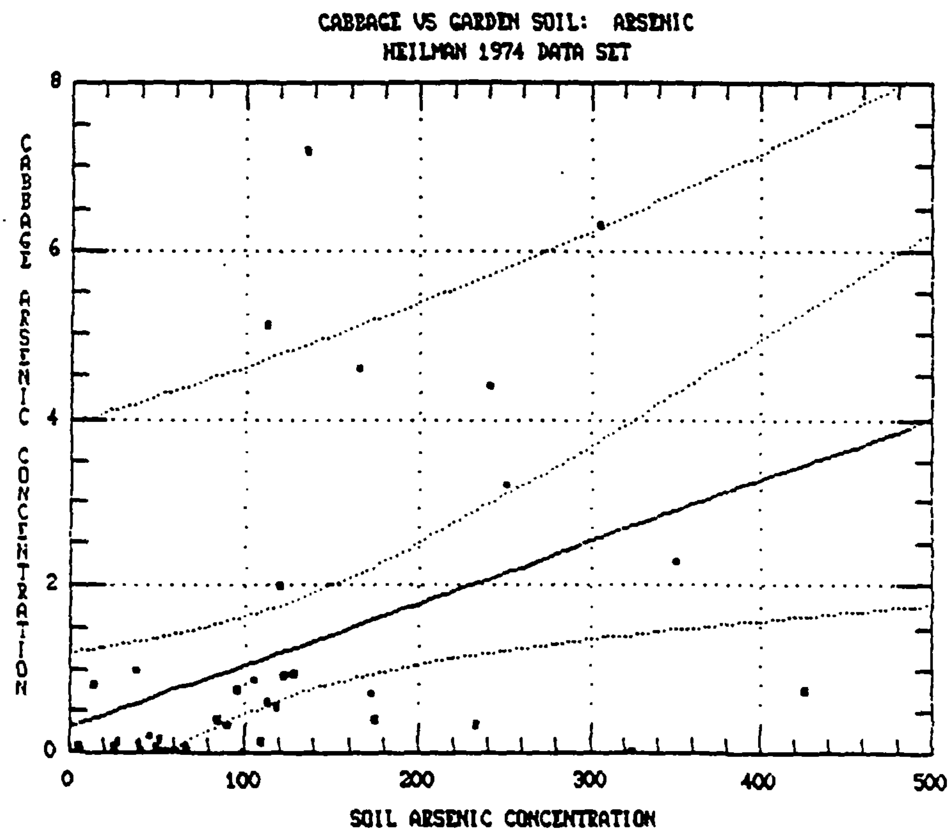
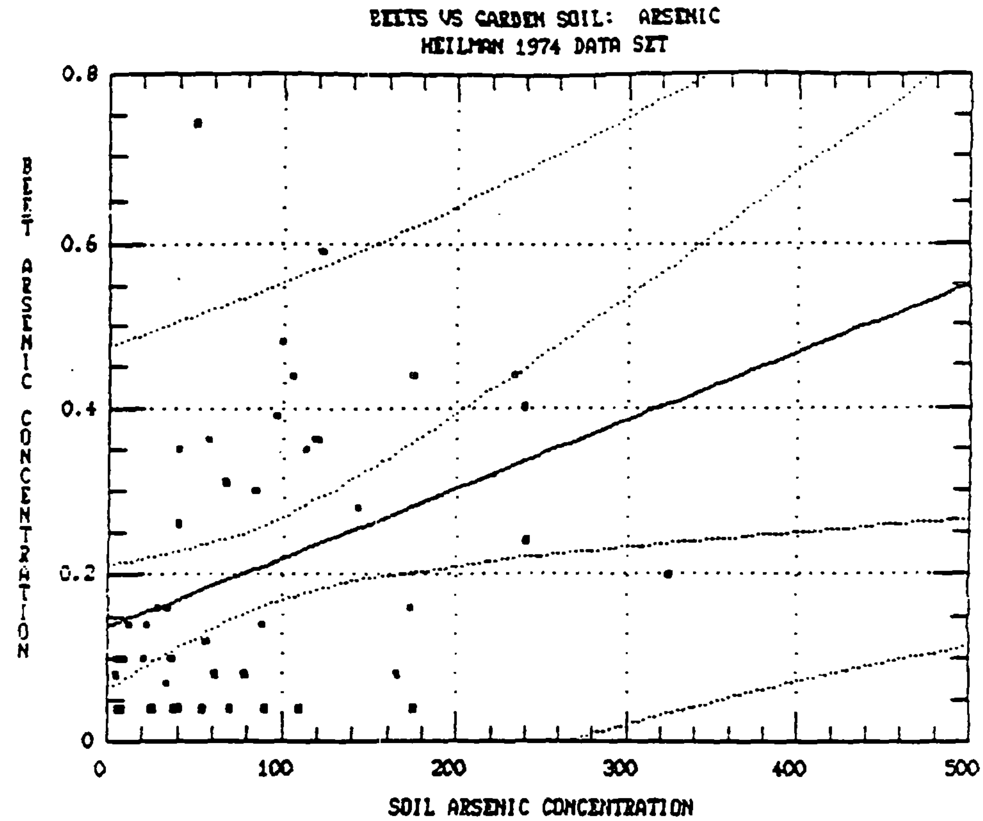


FIGURE E-4

VEGETABLE TISSUE VERSUS GARDEN SOIL
ARSENIC CONCENTRATIONS
HEILMAN 1974 DATA



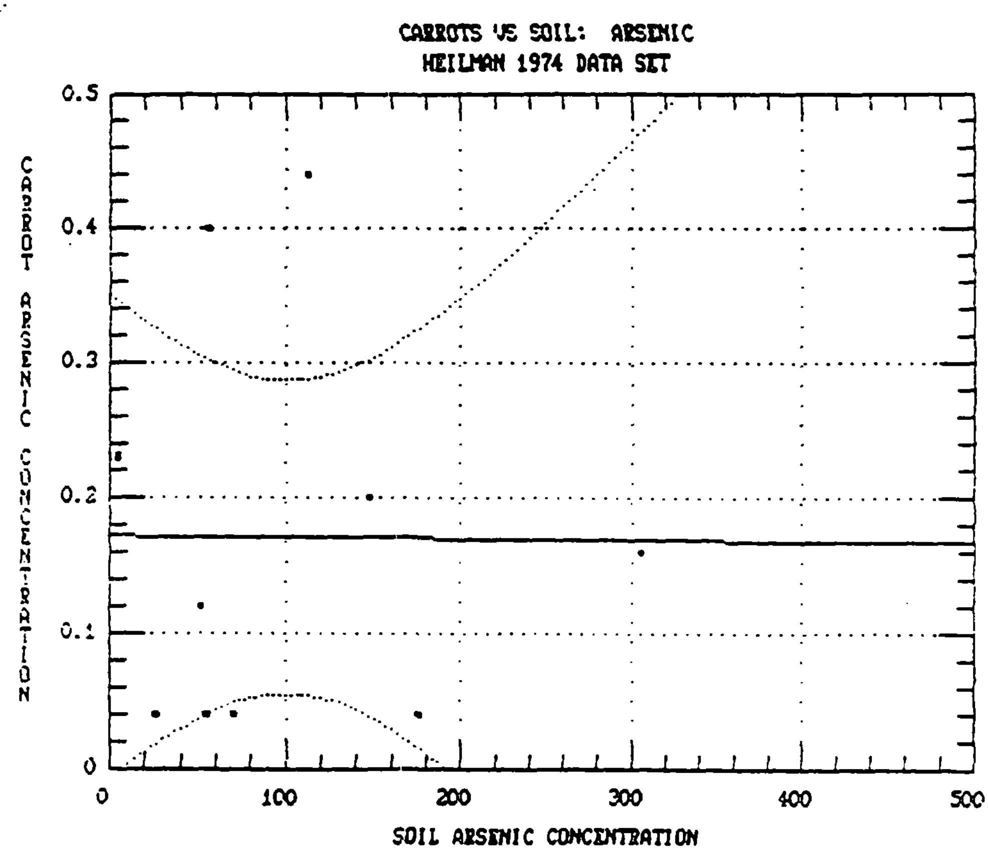
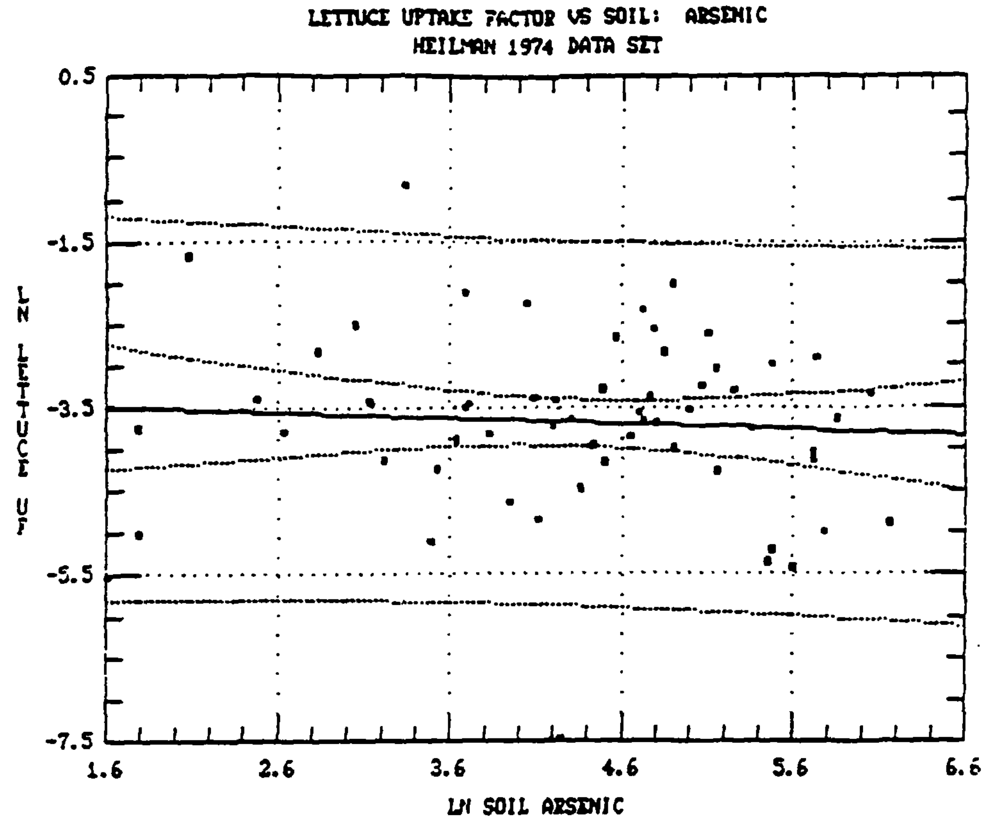


FIGURE E-4 (continued)

VEGETABLE TISSUE VERSUS GARDEN SOIL ARSENIC CONCENTRATIONS HEILMAN 1974 DATA



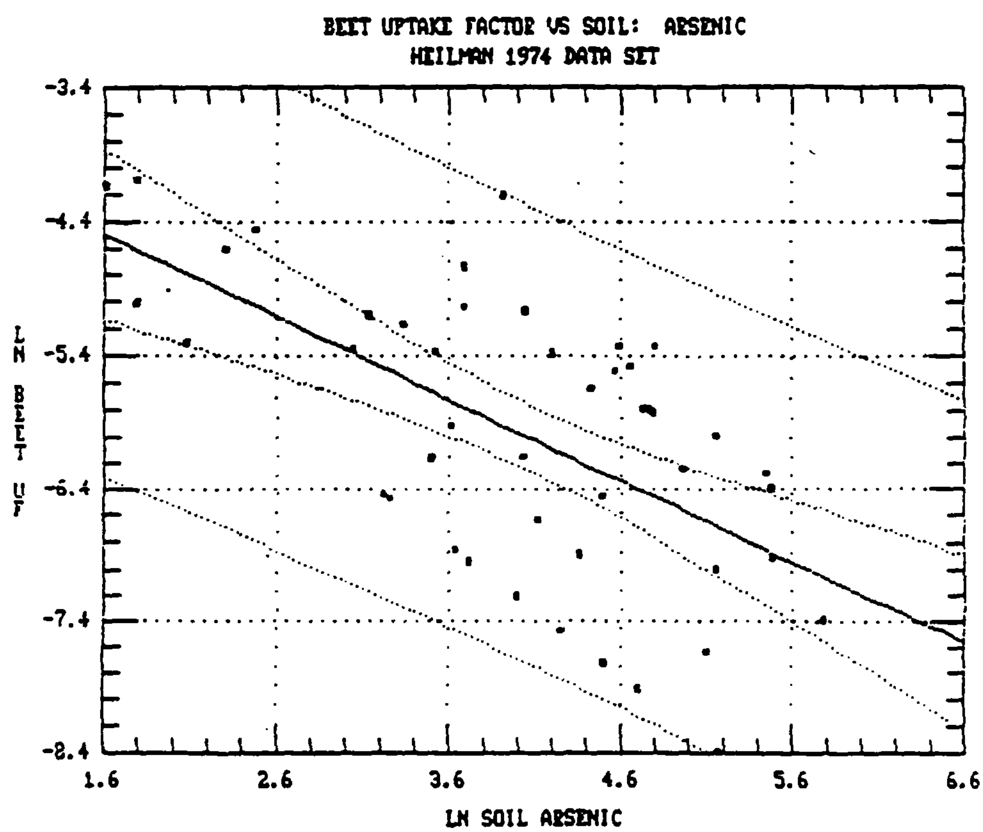
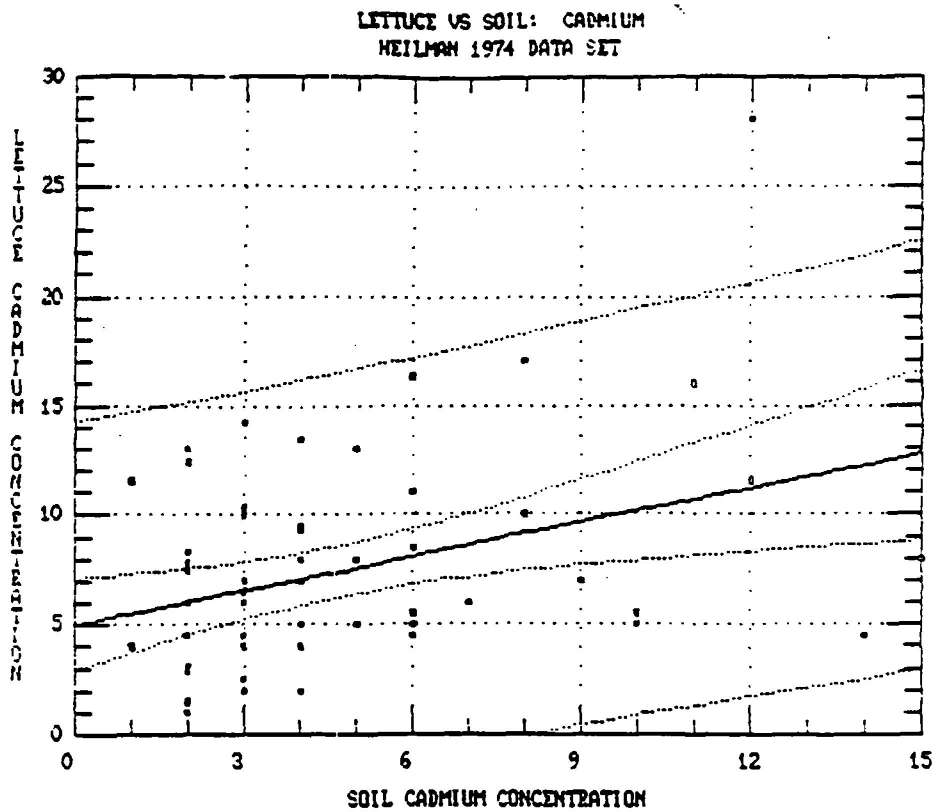


FIGURE E-5

UPTAKE FACTORS VERSUS GARDEN SOIL ARSENIC CONCENTRATIONS HEILMAN 1974 DATA



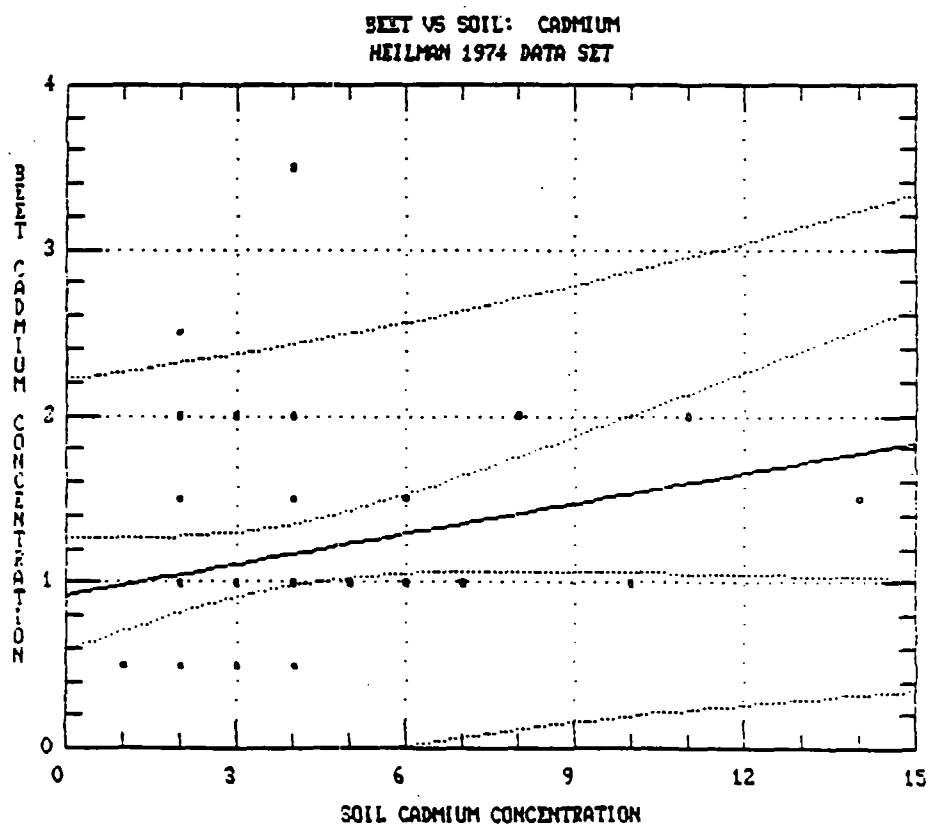
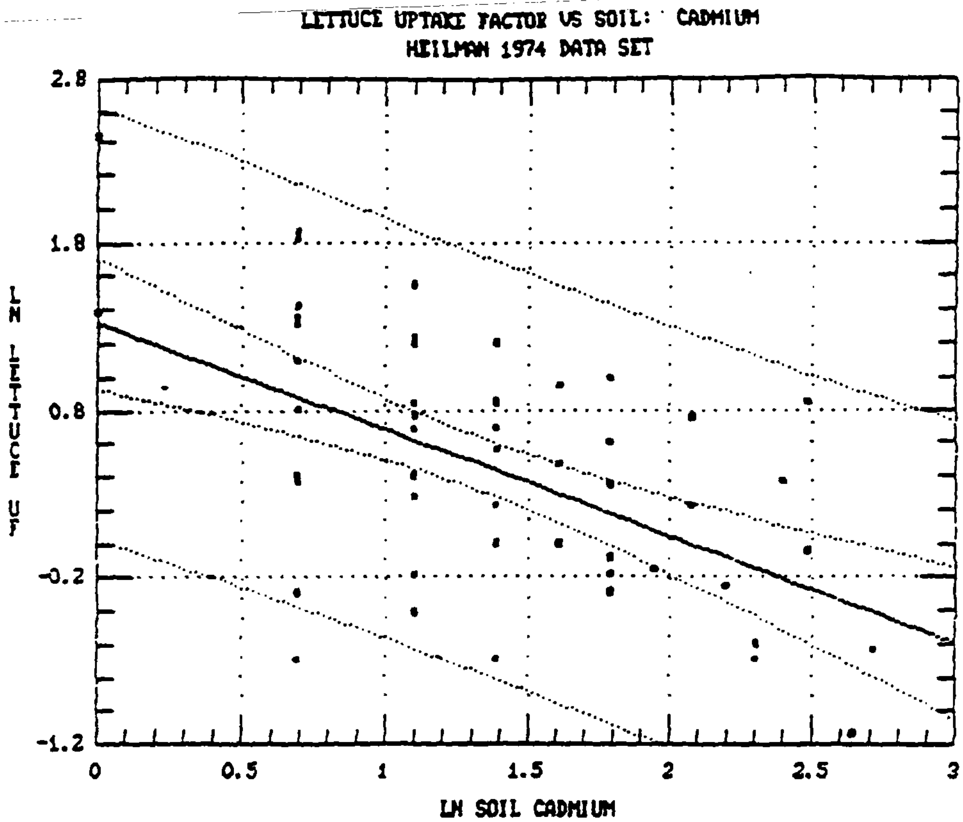


FIGURE E-6

VEGETABLE TISSUE VERSUS GARDEN SOIL CADMIUM CONCENTRATIONS HEILMAN 1974 DATA



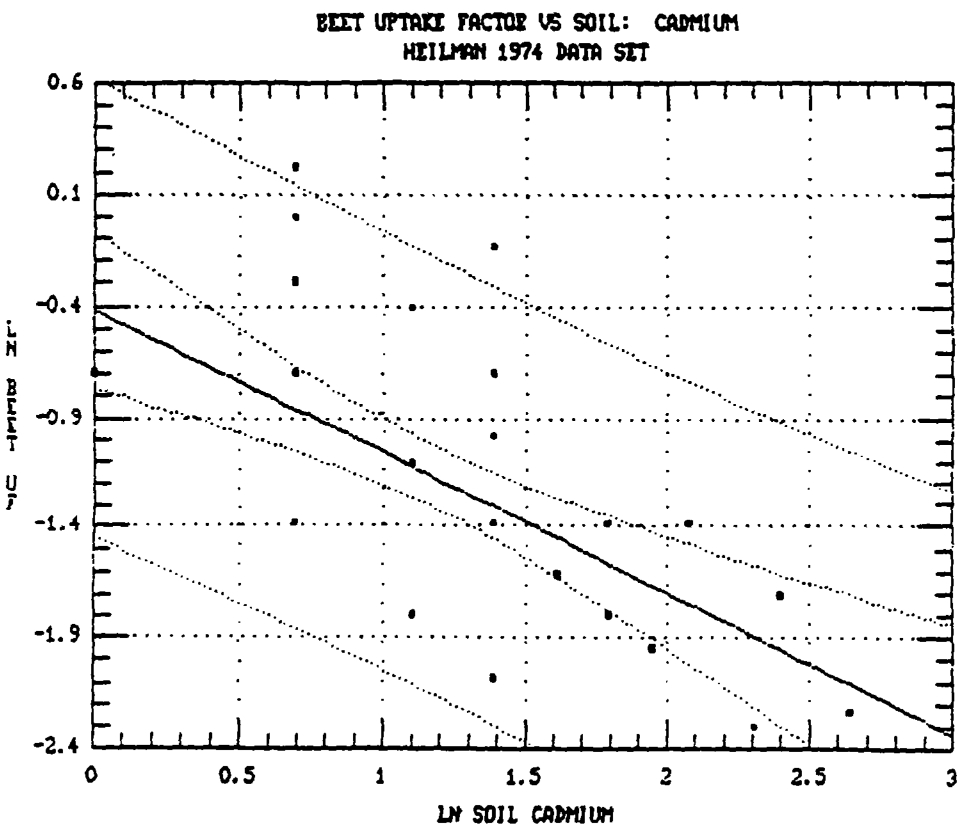
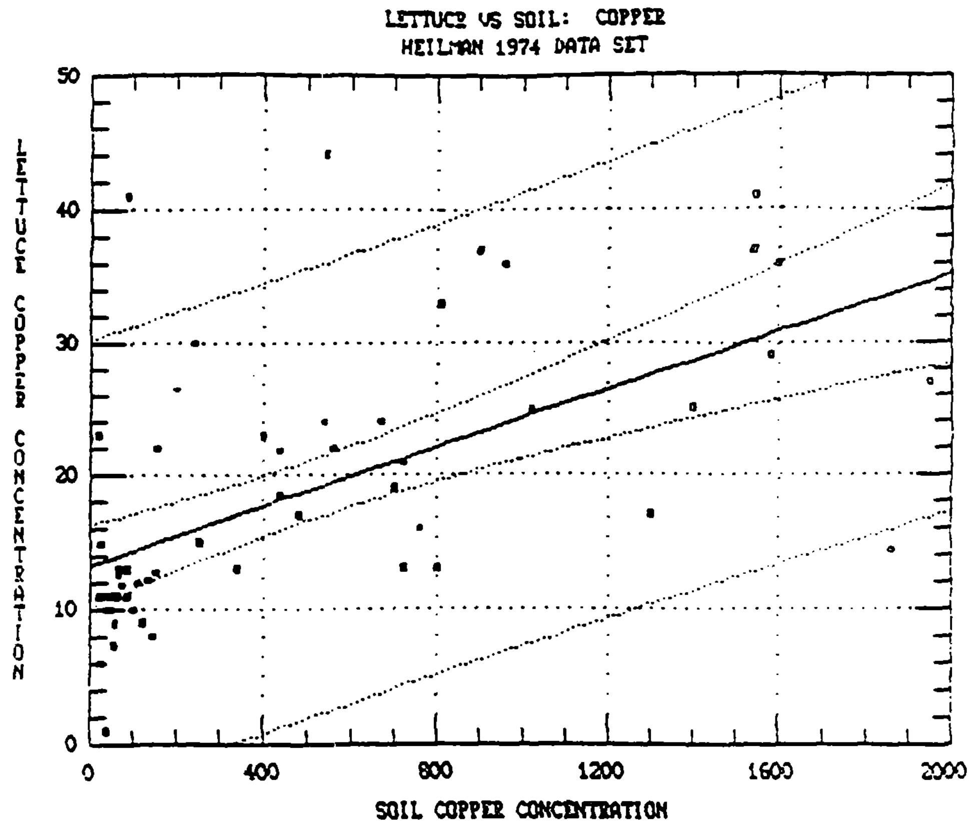


FIGURE E-7

UPTAKE FACTORS VERSUS GARDEN SOIL CADMIUM CONCENTRATIONS HEILMAN 1974 DATA



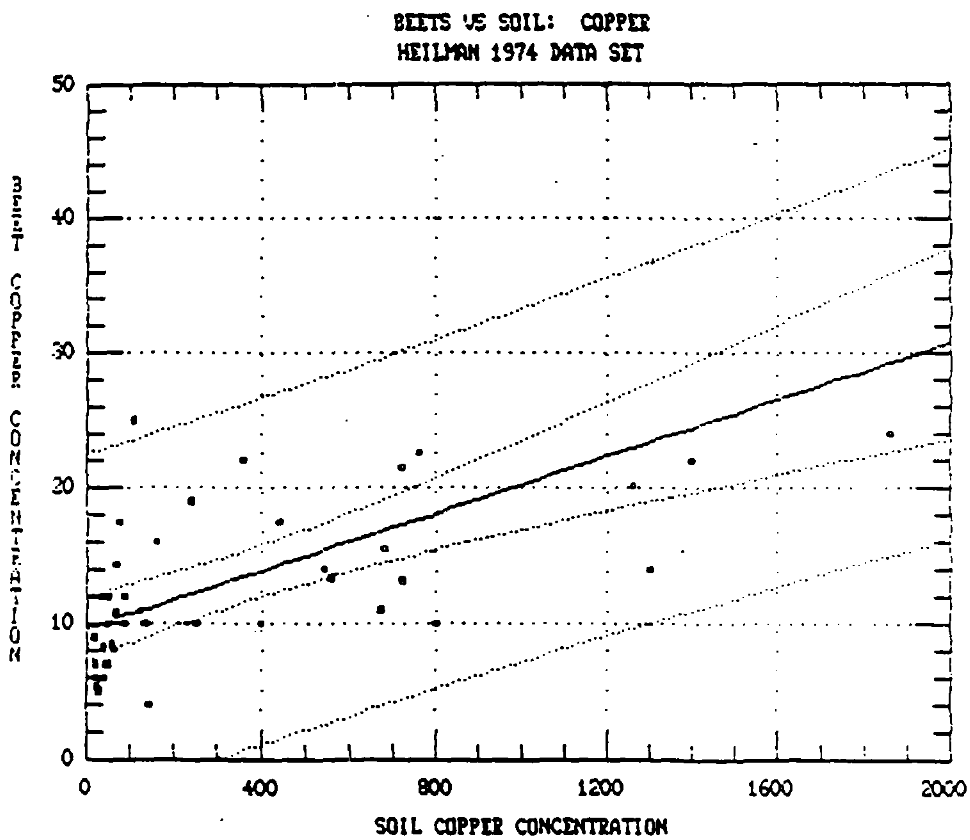
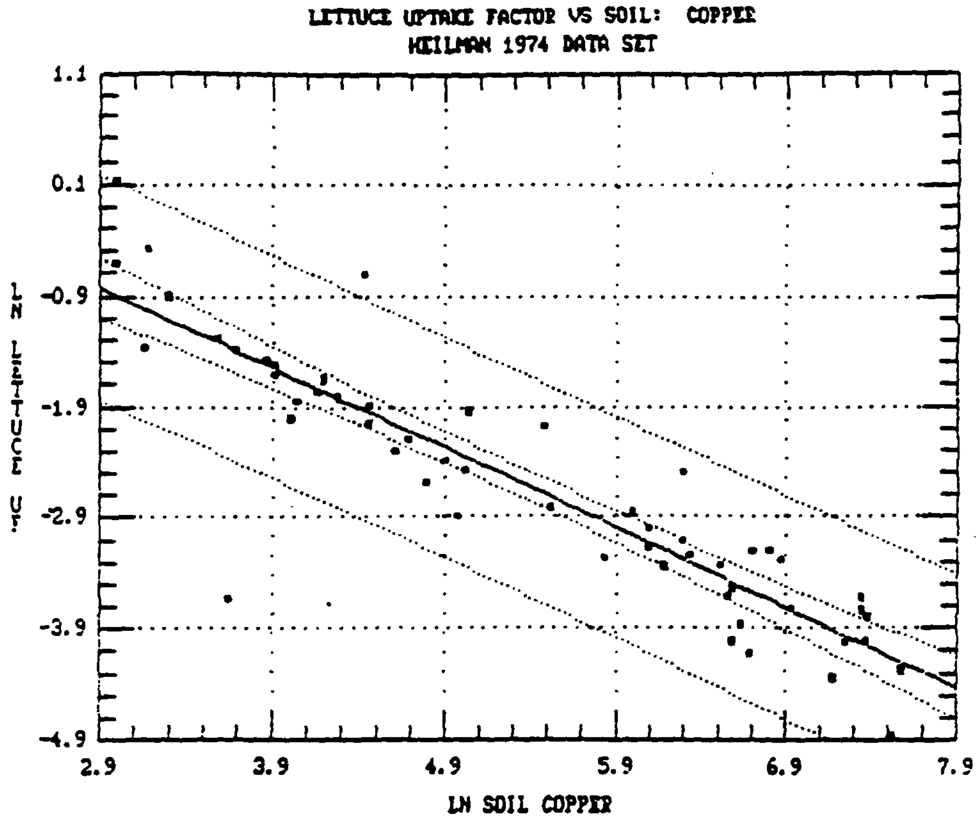


FIGURE E-8

VEGETABLE TISSUE VERSUS GARDEN SOIL COPPER CONCENTRATIONS HEILMAN 1974 DATA



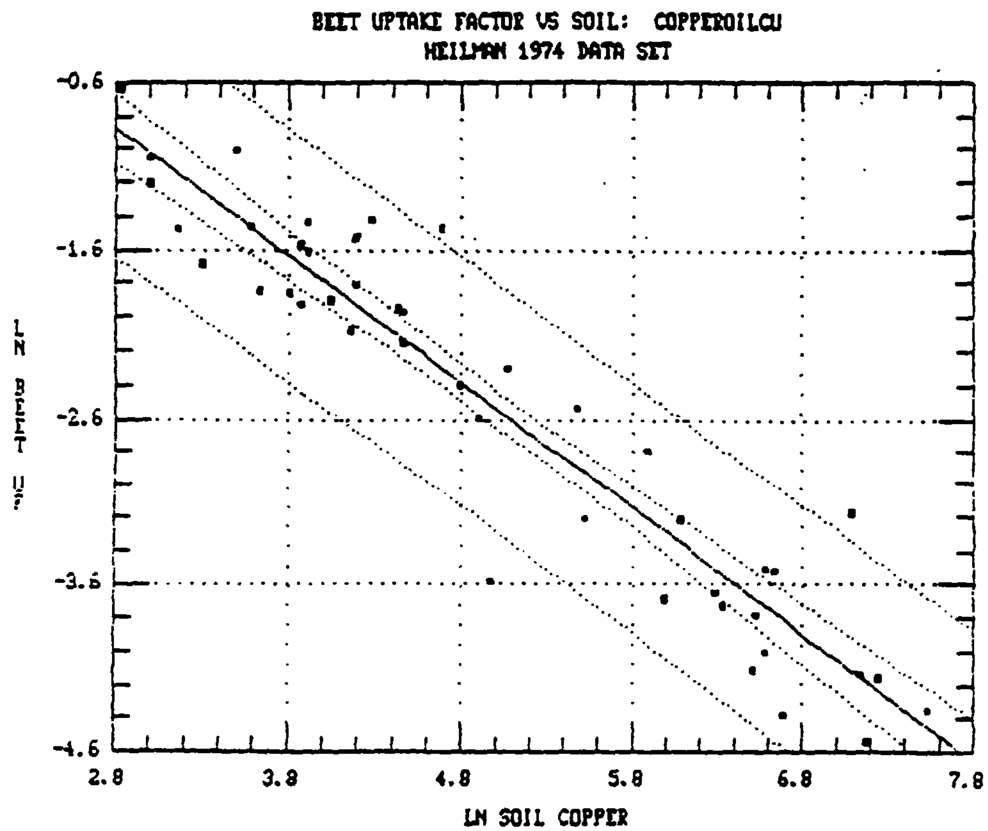
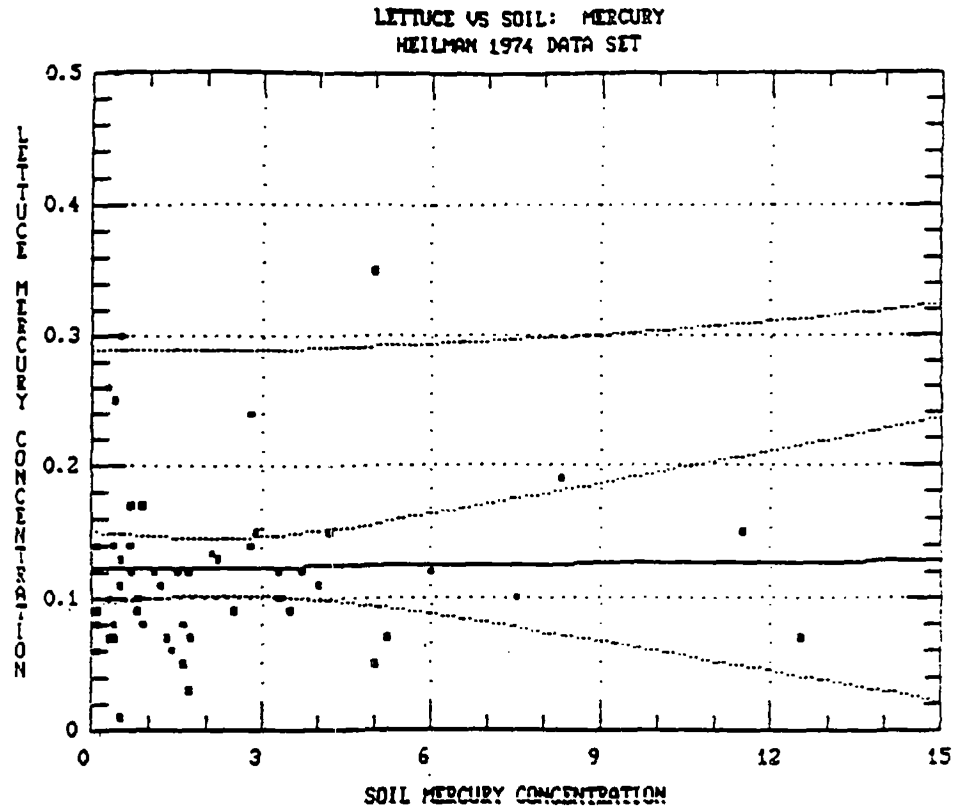


FIGURE E-9

UPTAKE FACTORS VERSUS GARDEN SOIL COPPER CONCENTRATIONS HEILMAN 1974 DATA



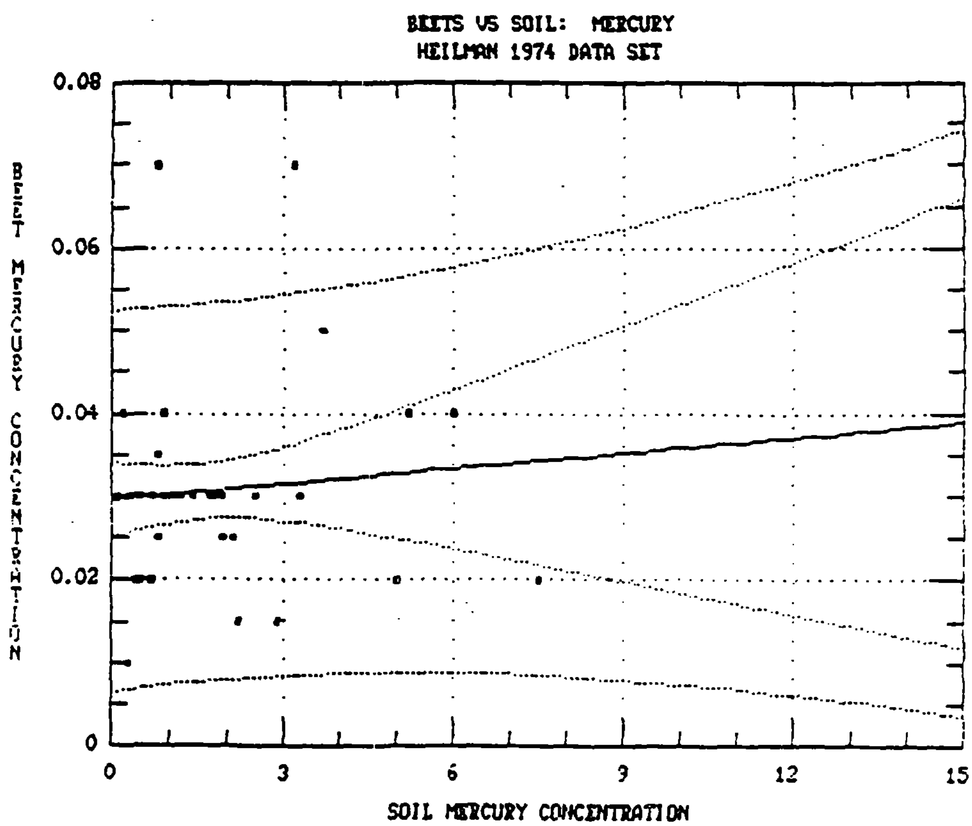
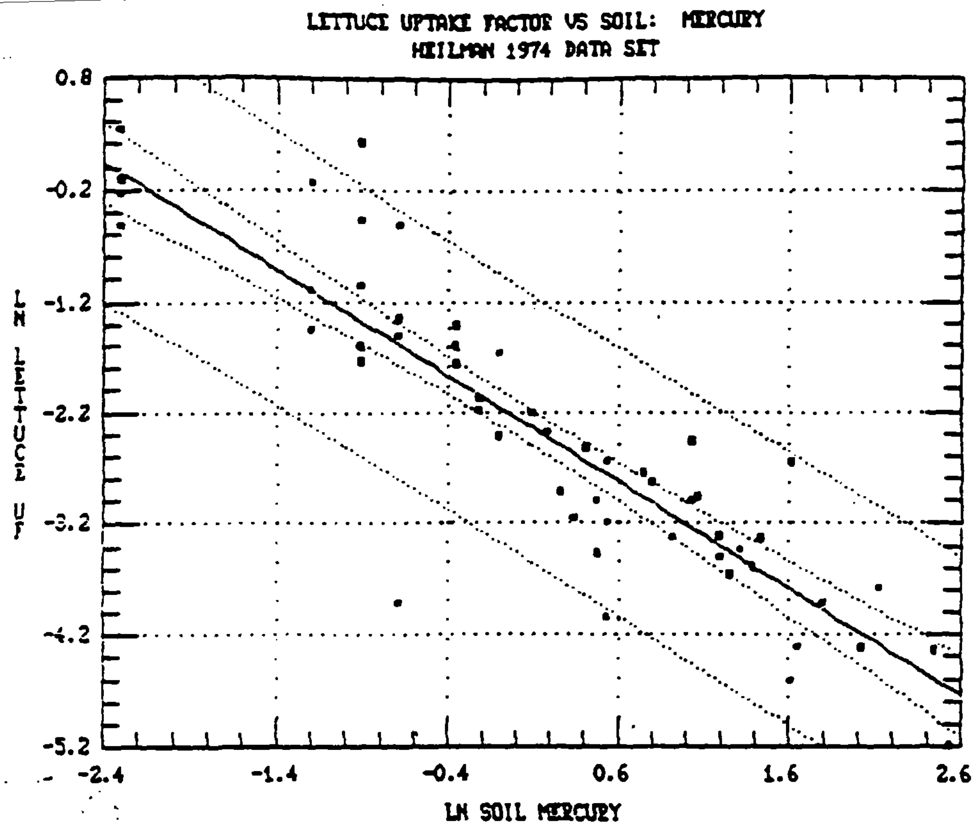


FIGURE E-10

VEGETABLE TISSUE VERSUS GARDEN SOIL
MERCURY CONCENTRATIONS
HEILMAN 1974 DATA



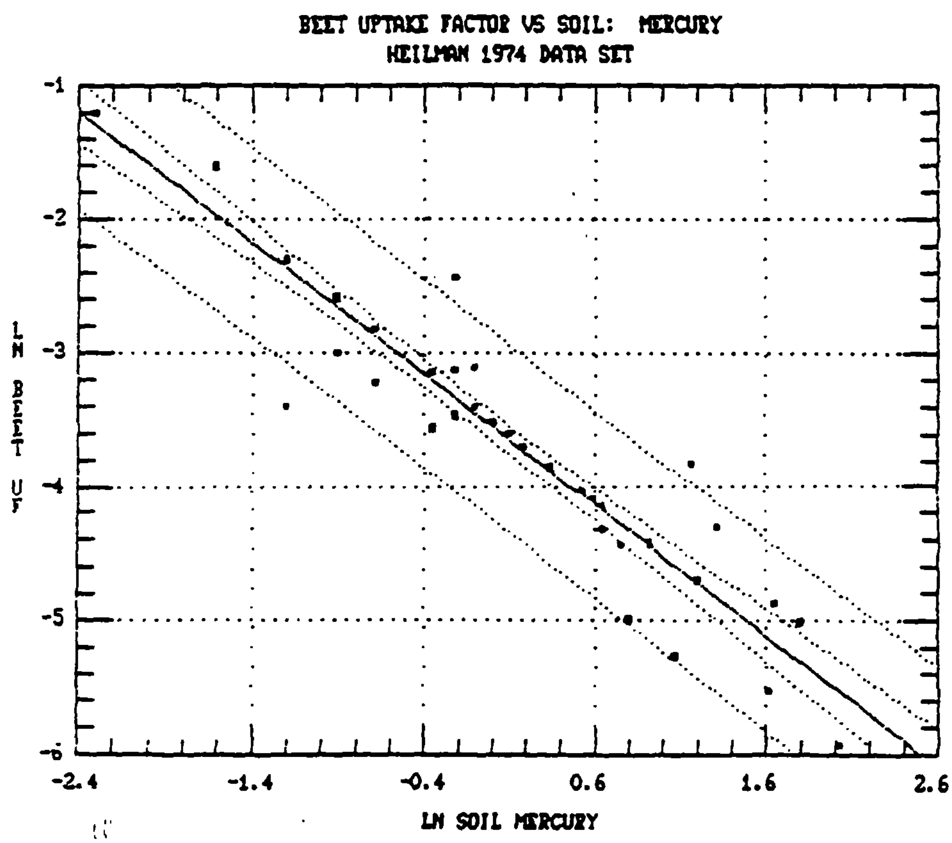


FIGURE E-11

UPTAKE FACTORS VERSUS GARDEN SOIL
MERCURY CONCENTRATIONS
HEILMAN 1974 DATA

The regression model results for all 36 cases evaluated (six vegetable types and six elements) are summarized in Table E-1. Except for the four leafy vegetables and arsenic, all of the results show regression slopes significantly different from (less than) zero (probability values p less than 0.01). The arsenic results in leafy vegetables, as noted above, are characterized by considerable scatter and none of the regression slopes is significantly different from zero. This implies that a model assuming slope of zero (i.e., a constant uptake factor and tissue concentrations varying linearly with soils) is appropriate for arsenic in leafy vegetables, but in no other cases.

By applying the regression models for arsenic, uptake factors at each of the arsenic soil concentrations evaluated in the risk assessment (see Appendix C) were calculated for each vegetable type. For the higher soil arsenic concentrations, it is noted that this calculation involves estimating beyond the range of the soil data on which the regression equations are based. By using these estimated uptake factors, tissue concentrations at the given soil concentrations were calculated. The results are shown in Table E-2. As discussed above, the variation in estimated uptake factors for leafy vegetables is small and tissue concentrations vary approximately with soil concentrations. For carrots (regression slope of -1.02), tissue concentrations are essentially constant (compare with the raw data shown in Figure E-4). For beets, tissue arsenic concentrations increase only very slightly with increasing soil concentrations.

2.2.2 Other Studies

Uptake factors calculated from the limited data available in the Ratsch (1974) study are very high compared with the results from Heilman and Ekuan (1977) described above. This is true for samples described as both washed and unwashed. The Ratsch (1974) and Heilman and Ekuan (1977) sampling occurred over the same general study area only 1 year apart, and such large differences would not have been expected. It is conceivable that the sample preparation for the Ratsch (1974) analysis (including washing) did not succeed in removing all adhering soil particles or deposited airborne particulates. The Heilman and Ekuan (1977) sampling also occurred in a labor strike year (1974) during July and early August, at least partly (if not totally) in a period when the smelter was not operating. This further suggests an effect of unwashed airborne deposition in the Ratsch (1974) study results, or of important foliar uptake from particulate deposition on plant leaves.

Uptake factors in the Lowry (1983) study also reflect some very high values and are generally higher than the Heilman and Ekuan (1977) results. Results for leafy and root vegetables and for subsets of those groups identified as lettuce and carrots for all six study areas are summarized in Figures E-12 and E-13. The smelter was operating during the period of sampling in 1983, as in the Ratsch (1974) study. The Lowry (1983) results for leafy vegetables are quite interesting when evaluated by area. For north Tacoma only (the area closest to the smelter) and for pooled areas other than north Tacoma and Vashon Island (least affected by smelter emissions), regression lines of log uptake factor versus log soil concentration are essentially flat (slope of approximately zero, uptake factor equal to a constant). However, the value of the uptake factor for north Tacoma samples is more than double that for less affected areas, which is itself double the value from the Heilman and Ekuan (1977) data set for lettuce or beet greens.

Uptake factors for root crop vegetables are also substantially higher than Heilman and Ekuan results, but with less difference between North Tacoma and more distant areas sampled by Lowry (1983).

In a speciation study for arsenic in various environmental media in the Ruston/Tacoma area, the Tacoma-Pierce County Health Department (TPCHD undated) also analyzed one archived sample from the 1983 Lowry garden vegetable study. The authors reported finding less than 4 percent of the arsenic that had previously been reported for that sample and they speculate that washing of samples prior to analysis in 1983 may have been incomplete. The general results for north Tacoma versus more distant areas sampled, as briefly discussed above, appear consistent with the inclusion of some soil particulates or airborne particulates contaminated with arsenic in some vegetable tissue samples. Foliar uptake from air deposited particulates (smelter emissions) also cannot be ruled out.

To test the relative effects of soil and airborne arsenic, Heilman and Ekuan (1977) grew vegetables in a greenhouse in Puyallup, where air concentrations of arsenic and other smelter-related contaminants were low, in soils collected from the areas near the smelter (arsenic concentrations in the range of 284 to 2,120 mg/kg). Arsenic concentrations in the plant tissue of these greenhouse vegetables were similar to levels found in the study area garden samples. The authors state that it appears likely that heavy metals in plant tissues are primarily the result of uptake of these elements from soils, with atmospheric contamination being of lesser importance. Substantial yield reductions in the higher soil arsenic samples, which exceeded levels included in the gardens surveyed, were also noted.

Ambient air concentrations within a mile of the smelter during the 1974 strike period were about 10 percent of levels after resumption of smelter operations (McClannan and Rossano 1975; see also PSAPCA 1981) but still several times higher than current levels. The conditions in the Ruston/North Tacoma study area during the strike period may have affected the conclusions reached in the greenhouse experiment and may account for much of the difference between Heilman and Ekuan's (1977) results and those of preceding and succeeding studies. This interpretation also suggests that the Heilman and Ekuan study results are the most applicable to current conditions among the three studies.

Table E-1
LOG-LOG REGRESSION MODEL RESULTS:
VEGETABLE UPTAKE FACTOR VERSUS SOIL[a]

CONTAINMENT	PLANT	INTERCEPT	SLOPE	R-SQUARED	P[b]	N
ARSENIC	chard	-5.63	0.19	1.8	0.67	13
	cabbage	-4.65	-0.17	1.5	0.47	38
	beet greens	-4.54	0.10	0.5	0.64	45
	lettuce	-3.38	-0.07	0.5	0.58	59
	beets	-3.51	-0.61	37.1	0.00001	46
	carrots	-2.09	-1.02	58.6	0.01	10
CADMIUM	chard	1.21	-1.00	66.2	0.0007	13
	cabbage	-0.07	-0.54	18.5	0.007	38
	beet greens	1.31	-0.72	24.4	0.0006	45
	lettuce	1.33	-0.64	29.9	0.00001	59
	beets	-0.42	-0.64	35.7	0.00001	46
	carrots	0.03	-0.90	67.9	0.003	10
COPPER	chard	0.78	-0.54	79.4	0.0001	12
	cabbage	-0.07	-0.59	77.0	0.0000	36
	beet greens	1.42	-0.72	79.2	0.0000	44
	lettuce	1.27	-0.72	81.6	0.0000	55
	beets	1.24	-0.76	89.1	0.0000	45
	carrots	2.09	-1.03	98.1	0.0000	10
LEAD	chard	2.44	-0.99	93.9	0.0000	13
	cabbage	1.51	-0.88	74.5	0.0000	38
	beet greens	3.39	-1.11	85.5	0.0000	45
	lettuce	2.62	-1.00	89.6	0.0000	59
	beets	1.24	-0.92	70.1	0.0000	46
	carrots	2.01	-1.13	93.0	0.00001	10
MERCURY	chard	-2.11	-0.81	89.1	0.0000	13
	cabbage	-2.86	-0.79	67.1	0.0000	38
	beet greens	-2.45	-1.00	81.4	0.0000	45
	lettuce	-2.26	-0.96	80.4	0.0000	57
	beets	-3.55	-0.98	90.6	0.0000	46
	carrots	-2.68	-1.34	78.4	0.0007	10
ZINC	chard	5.54	-1.00	59.8	0.002	13
	cabbage	2.83	-0.74	34.7	0.0001	38
	beet greens	4.63	-0.88	38.3	0.00001	45
	lettuce	4.77	-1.01	61.8	0.0000	59
	beets	3.32	-0.82	63.7	0.0000	46
	carrots	2.79	-0.84	83.2	0.0002	10

a Data from Heilman 1974 Garden Vegetable Study (Heilman and Ekuan 1977).
b Probability values (p) are rounded to significant figures shown.

Table E-2
PREDICTED UPTAKE FACTORS AND VEGETABLE CONCENTRATIONS[a]

PLANT		SOIL CONCENTRATIONS USED IN RISK ASSESSMENT				
		1600 mg/kg	800 mg/kg	500 mg/kg	300 mg/kg	140 mg/kg
Arsenic Uptake	chard	0.0147	0.0129	0.0118	0.0107	0.0092
	cabbage	0.0028	0.0031	0.0034	0.0037	0.0042
	beet greens	0.0225	0.0210	0.0200	0.0190	0.0176
	lettuce	0.0201	0.0211	0.0218	0.0226	0.0239
	beets	0.00032	0.00050	0.00066	0.00090	0.00144
	carrots	0.00007	0.00014	0.00022	0.00037	0.00081
Tissue Concentration (mg/kg/dw)	chard	23.5	10.3	5.9	3.2	1.3
	cabbage	4.4	2.5	1.7	1.1	0.6
	beet greens	36.0	16.8	10.0	5.7	2.5
	lettuce	32.1	16.9	10.9	6.8	3.3
	beets	0.5	0.4	0.3	0.3	0.2
	carrots	0.1	0.1	0.1	0.1	0.1

a Based on regression models from Heilman 1974 data

3.0 DISCUSSION

The representativeness of pre-shutdown garden vegetable data sets for current, post-shutdown conditions in the community surrounding the Asarco smelter was considered. Some degree of acidification effects resulting from smelter SO_x emissions may have occurred, especially with respect to foliar uptakes. However, available data indicate that the pH of garden soil in 1974 was higher than that of surface soil at present (1990 samples) in the community and that pH was not lower in areas most likely to have been affected by smelter emissions. This finding is consistent with the view that normal gardening practices probably modify native soils and limit potential soil acidification effects.

Data collection in 1974 occurred at the time of a strike that shut down smelter operations temporarily. Ambient air SO_x and arsenic concentrations in the community were much lower during the strike period (90 percent reduction) than during smelter operations. Ambient air levels are currently lower than they were during the 1974 strike period. As a result, the data

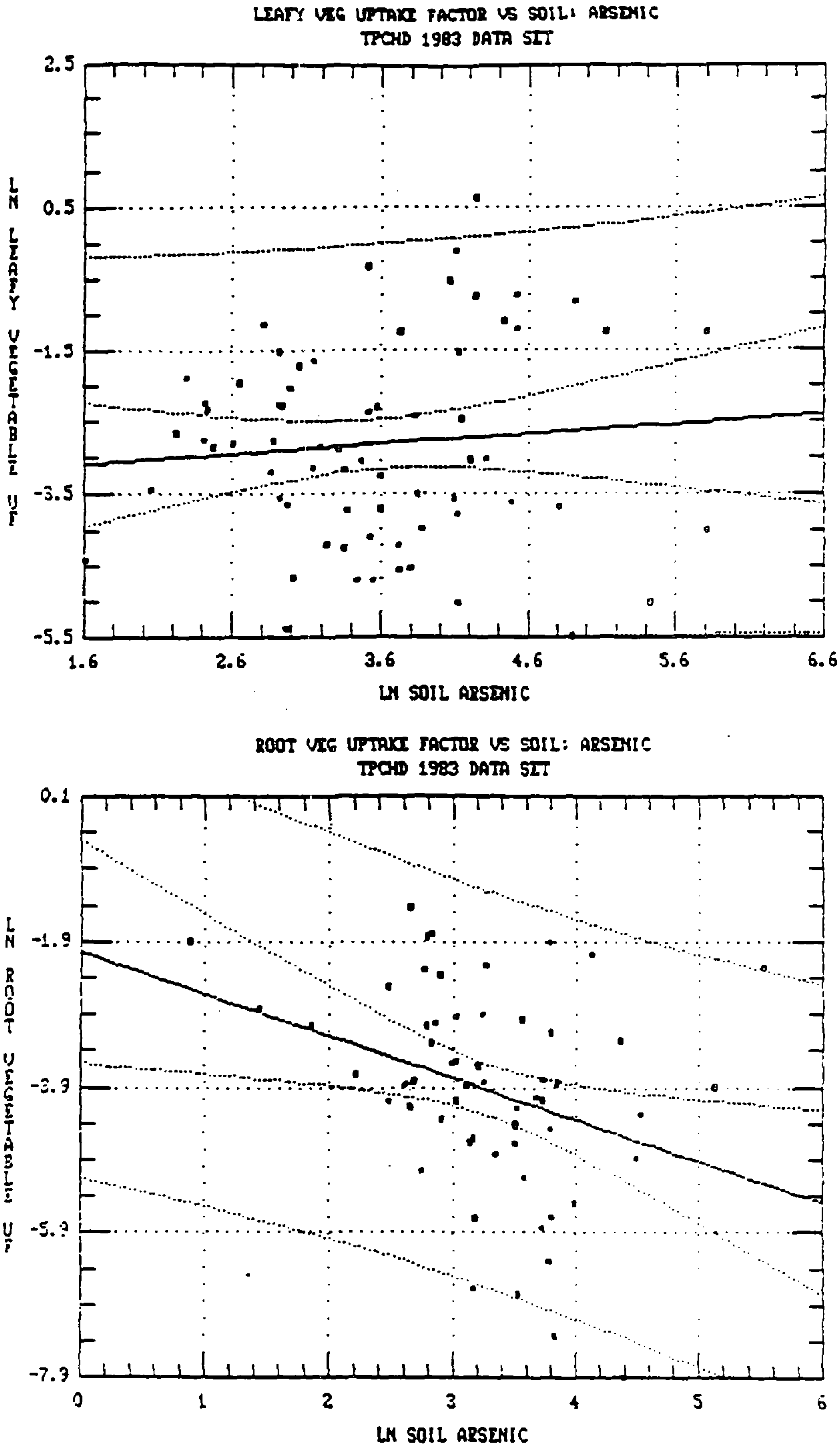
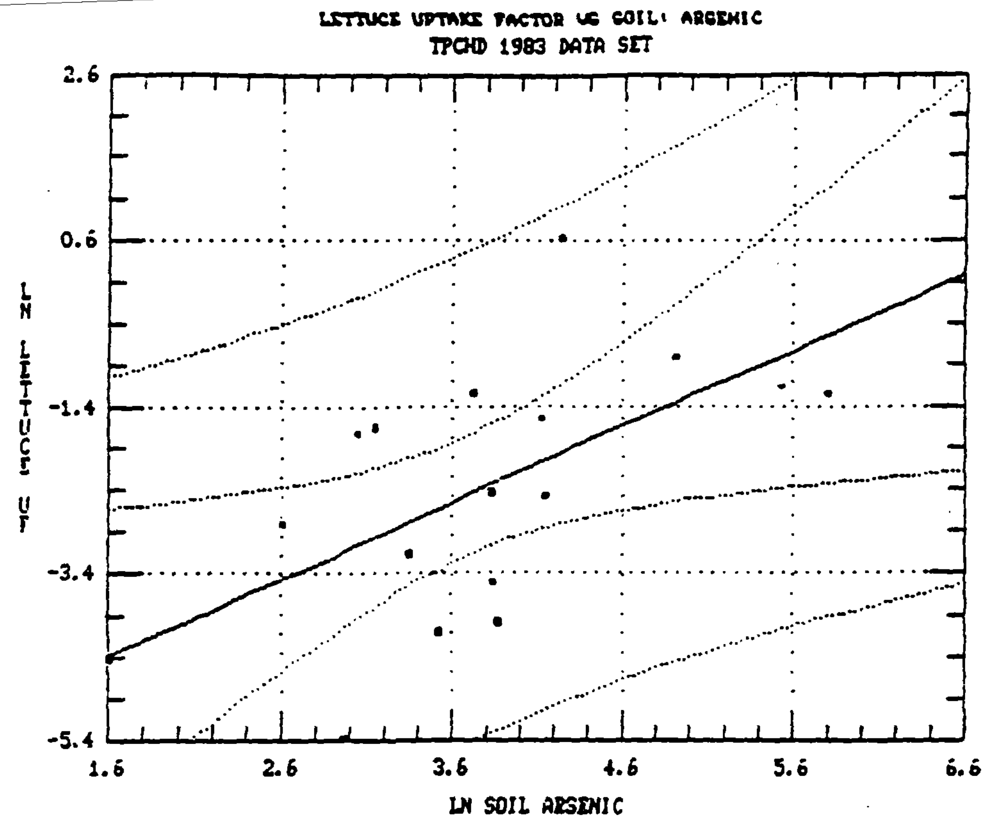


FIGURE E-12

VEGETABLE TISSUE VERSUS GARDEN SOIL
ARSENIC CONCENTRATIONS
TPCHD 1983 DATA



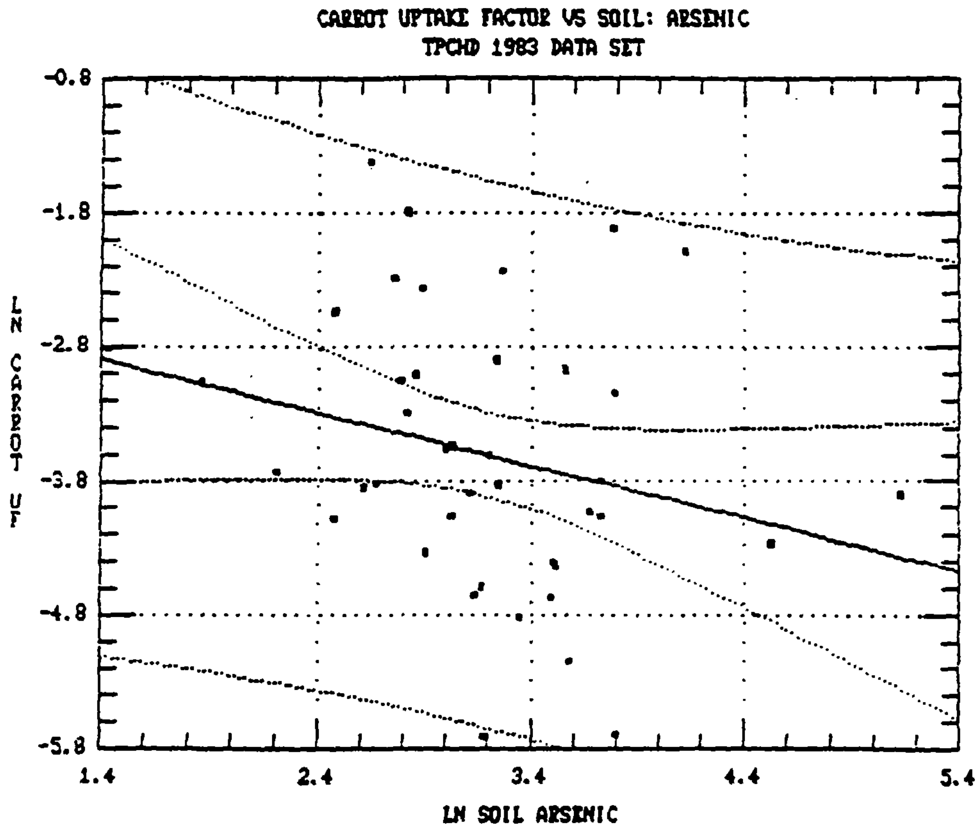


FIGURE E-13

UPTAKE FACTORS VERSUS GARDEN SOIL ARSENIC CONCENTRATIONS TPCHD 1983 DATA from the 1974 study more nearly represent early post-shutdown than operating conditions. The reduction in air concentrations may have limited any potential acidification effects, as well as the contributions of deposited particulates or foliar uptake to the measured vegetable tissue concentrations. A 1974 greenhouse experiment by Heilman and Ekuan (1977) also demonstrated that uptake was similar in field and greenhouse vegetables, indicating that soil uptake rather than air deposition or foliar uptake was the more important pathway for metals in vegetable tissues (at that time).

Acidification effects would not be expected to affect only one of the smelter-related contaminants (e.g. arsenic). The total Heilman and Ekuan (1977) data set, including the results for arsenic and five other metals, provides a strikingly consistent set of results. Data from areas near the smelter and more distant areas, including control sites unaffected by the smelter, combine to produce a series of very good fits (high r-squared values) to a log-log regression model for uptake factors versus soil concentrations. This pattern would not be expected if acidification effects in part of the sampling area were substantial.

Many literature references cite the phytotoxicity of arsenic as a limiting factor for plant uptake and possible human exposures. Phytotoxic effects have been observed at soil concentrations well below those existing in areas close to the smelter. There have been some early anecdotal reports for the Ruston/North Tacoma study area that certain vegetable types (e.g., legumes) were absent, although supporting evidence for such statements is slight. In their greenhouse study, Heilman and Ekuan (1977) demonstrated significant yield reductions for plants grown in soil samples from the community with arsenic concentrations above about 300 mg/kg (concentrations of other metals such as cadmium, copper, lead, mercury, and zinc were also significantly elevated.)

Phytotoxicity is a limiting factor for arsenic uptake and human exposures; if garden vegetables do not grow or grow poorly and are not eaten, exposures will not occur. However, the garden vegetables sampled by Heilman and Ekuan (1977) from community gardens near the smelter in 1974 represented plants successfully grown (and available for eating) in soils whose arsenic concentrations often exceeded the cited thresholds for arsenic phytotoxicity. The garden soils sampled included seven locations with arsenic concentrations above 300 mg/kg, up to a maximum of 470 mg/kg; vegetable samples were available for analysis at those sites, even though soil arsenic levels were higher than those shown in the greenhouse study to result in yield reductions. Different plants have different sensitivities to arsenic contamination. To some degree, gardeners may accommodate high soil arsenic levels by adjusting the plants cultivated. Phytotoxicity limits and effects cannot be precisely specified.

At increasing soil arsenic concentrations, phytotoxic effects will ultimately limit plant growth and potential human exposures. Extrapolating the uptake factor versus soil concentration relationships demonstrated in the regression analyses beyond the range of soil concentrations actually included in the data set does not account for increasingly likely phytotoxic effects. In ignoring phytotoxicity, such extrapolation represents an upper bound estimate of possible intakes of contaminants in home-grown garden vegetables. This conservatism is of most concern for sites where surface soils are in the upper 10 or 20 percent of the distribution for soil arsenic in the study area as currently defined, where arsenic levels fall at the upper end of or above the range within the Heilman and Ekuan (1977) data set. Exposure estimates based on upper percentile soil arsenic concentrations should be qualified with respect to possible conservatism resulting from not considering phytotoxicity effects.

Intake estimates based on arsenic concentrations for nongarden soil samples also may not adequately account for the changes in soils due to normal gardening practices. Arsenic concentrations in home gardens may often be lower than those in nearby yards as a result of adding soil amendments, tilling, or other typical gardening practices. Matched garden soil and yard soil data sets are not available to evaluate the possible degree of such effects.

Plant uptake of arsenic has been cited in the literature as more closely related to measurements of "available" soil arsenic rather than total soil arsenic (Woolson 1973; Walsh et al. 1977). The concept of availability takes into account that normal soil chemistry and fate processes may result in binding of arsenic or other elements in a manner that makes them relatively immobile, insoluble, and unavailable for uptake by plants under normal environmental conditions. None of the site-specific soil data sets provide information on "available" arsenic levels.

Smelter emissions and deposition of arsenic to surface soils during the period of smelter operations probably contributed an increment of highly available arsenic to existing soil arsenic reservoirs of much lower availability. Fate processes that led to binding of arsenic in soils are believed to have occurred relatively rapidly (e.g., within a year). Therefore, even in 1974 at the time of garden soil and vegetable sampling, most of the soil arsenic reflected historically deposited, relatively unavailable arsenic. Since smelter shutdown there may have been a decrease in the percentage of available arsenic in garden soils, but probably not a large one. As a result, uptake factors estimated from 1974 data could be somewhat conservative for current conditions because of changes in arsenic availability.

The chemical form of arsenic in plant tissues has been discussed by Pyles and Woolson (1982), who suggest that at least some plant arsenic occurs in complex organic arsenic compounds. The total arsenic concentrations in their experimentally treated vegetables were low. However, in a speciation study conducted about 1984 on three field-grown vegetable samples from the Ruston/North Tacoma study area (TPCHD undated), the total methylated arsenic (mono- and dimethylarsenic) was not detected in two of the samples and accounted for only 10 percent of the arsenic in the third (lettuce) sample; remaining detected arsenic was inorganic. (Neutron activation analyses indicated that extracted arsenic was less than one-third of total arsenic in the three vegetable samples). Other unpublished data reviewed by EPA (USEPA 1988) are also cited as indicating that much of the arsenic occurring in vegetables is in an organic form. For this risk assessment, it was assumed that all arsenic in plant tissues (predicted on the basis of uptake factor regression analyses) is inorganic.

Uptake factors vary considerably in the Heilman and Ekuan (1977) data among samples of the same type of vegetable and for the same element; this is particularly true for leafy vegetables and arsenic. Many factors other than (total) soil concentration probably contribute to this variability. Variability was considered with respect to what value or values for uptake factors represent a reasonable maximum exposure as discussed in current EPA guidance for risk assessment (USEPA 1989a). For example, instead of the best-fit regression equation for uptake factor, use of the 95 percent confidence interval for the regression estimate, or the 95th percentile value, was considered. Current study area conditions may reflect somewhat lower uptake values than existed in 1974 because of lower air concentrations of smelter-related contaminants, less acidification potential, and lower overall availability of soil arsenic. Within the garden vegetable exposure model, uptake factors for classes of vegetables (e.g., leafy or root vegetables) are based on higher species results from the Heilman and Ekuan (1977) data set (e.g., lettuce rather than cabbage). The exposure model also conservatively estimates gardening and vegetable ingestion over a prolonged time period (30 years). Finally, potential phytotoxic effects that would limit exposure are not considered in the uptake factor estimates. As a result, it was concluded that the uptake factors representing reasonable maximum exposures would be based on the best-fit regression equations. Uptakes and vegetable tissue concentrations at a specific site may exceed those values at times, given the variability in the 1974 data set.

The overall conclusion of the data evaluations is that in the absence of any post-shutdown garden vegetable data, it is reasonable to use the Heilman and Ekuan (1977) garden soil and vegetable data from 1974 to estimate potential uptake factors and human exposures from eating home-grown produce.

4.0 RISK ASSESSMENT UPTAKE FACTORS

The uptake factors for arsenic in leafy vegetables are assumed to be constant, based on the Heilman and Ekuan (1977) data, at a value reflecting estimated uptake factors for lettuce and beet greens. The selected value of 0.02 is one-half of the value cited in Baes et al. (1984). The use of a constant uptake factor results in vegetable tissue concentrations that vary linearly with soil concentrations.

The uptake factors for root crops are based on results for beets from the Heilman and Ekuan data (see Tables E-1 and E-2). They vary from 0.0003 at 1,600 mg/kg soil arsenic to 0.0014 at 140 mg/kg. These values result in root crop tissue concentrations that increase very slowly with increasing soil concentrations. These uptake factors compare with a value of 0.006 cited in Baes et al. (1984).

The uptake factors for root crops are also assumed to apply to potatoes, legumes, and "fruity" vegetables (e.g., tomatoes, squash). Data for these additional types of vegetables are quite limited (especially site-specific data) and consequently uncertainties for their uptake are higher than for leafy or root crops. From data reported by Walsh et al. (1977) for peas grown on an arsenic-treated plot, the uptake factor was calculated to be about 0.006 (versus the 0.0014 estimated here). Woolson (1973) provides regression equations relating edible portions of selected vegetables to available soil arsenic in a treated-soil greenhouse experiment using three different soils. Assuming that overall available arsenic is 25 percent of total soil arsenic as applied [Woolson (1973) provides data showing time trends in available arsenic], estimated uptake factors at 150 mg/kg total soil arsenic are about 0.005 for tomatoes, 0.01 for lima beans, and 0.05 for green beans.

Eating garden vegetables, especially unwashed vegetables, may result in some additional intakes of contaminated soils, at concentrations far higher than the vegetable tissue concentrations. The garden vegetable exposure model does not account for soil intakes, except as they are included within the data set used to derive the uptake factors. Such additional soil ingestion in effect contributes to somewhat higher soil contact rates within the soil ingestion exposure model for those residents eating home-grown produce, and could increase overall exposure for populations consuming unwashed garden vegetables.

APPENDIX E ATTACHMENT:
HOME GARDEN VEGETABLE CONSUMPTION RATE

The estimated arsenic exposure due to consumption of home grown garden vegetables is calculated by multiplying the concentration of arsenic in each plant group by the home-grown amount of each contaminated plant group consumed daily. The concentration of arsenic in plant tissues is calculated using the site-specific uptake factors from Appendix E. The amount of home grown garden vegetables consumed is estimated using data found in the EPA office of Pesticide Programs' Tolerance Assessment System (TAS) and summarized in "Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions" (USEPA 1990a). Frequency distributions for consumption rates of 7 classes of vegetables are listed based on an analysis of the USDA Nationwide Food Consumption Survey (NFCS) of 1977-78 (USDA 1983). The data represent a three-day consumption period during April 1977 through March 1978 for 30,770 individuals surveyed. Tables E-3 through E-7 show the total dietary consumption rates by age groups for five classes of vegetables and the calculations to derive consumption rates for the 2 age groups of concern (0-6 years and 6-30 years) in this risk assessment. The consumption rates listed in the five tables are cited in the original reference as 70-75th percentile values.

Table E-3
CALCULATION OF CONSUMPTION RATE FOR HOMEGROWN VEGETABLES:
FRUITY PLANTS

Age Group (years)	70-75th percentile Consumption Rate[a] (g dw/kg bw/day)	Body Weight (kg)	Age Specific Intake (g dw/day)	Exposure Duration Averaging Factor	Time Weighted Average Daily Intake (g dw/day)
13-30	0.105[b]	70	7.35	(18 yrs/24 yrs)	5.5
7-12	0.19	70	13.3	(6 yrs/24 yrs)	3.3
1-6	0.24	15	3.6	(5 yrs/6 yrs)	3.0
0-1	0.07	15	1.05	(1 yrs/6 yrs)	0.18

CONSUMPTION RATE:

6-30 yrs = (5.5 g dw/day + 3.3 g dw/day) = 8.8 g dw/day
0-6 yrs = (3.0 g dw/day + 0.18 g dw/day) = 3.2 g dw/day

a Source: Methodology for Assessing Health Risks Associated with Indirect Exposures to Combustor Emissions (USEPA 1990a).
b Average for males and females.

Table E-4
CALCULATION OF CONSUMPTION RATE FOR HOMEGROWN VEGETABLES:
LEAFY PLANTS

Age Group (years)	70-75th percentile Consumption Rate[a] (g dw/kg bw/day)	Body Weight (kg)	Age Specific Intake (g dw/day)	Exposure Duration Averaging Factor	Time Weighted Average Daily Intake (g dw/day)
13-30	0.02	70	1.4	(18 yrs/24 yrs)	1.05
7-12	0.02	70	1.4	(6 yrs/24 yrs)	0.35
0-6	0.02	15	0.3	(6 yrs/6 yrs)	0.3

CONSUMPTION RATE:

6-30 yrs = (1.05 g dw/day + 0.35 g dw/day) = 1.4 g dw/day
0-6 yrs = 0.3 g dw/day

a Source: Methodology for Assessing Health Risks Associated with Indirect Exposures to Combustor Emissions (USEPA 1990a).

Table E-5
CALCULATION OF CONSUMPTION RATE FOR HOMEGROWN VEGETABLES:
ROOT PLANTS

Age Group (years)	70-75th percentile Consumption Rate[a] (g dw/kg bw/day)	Body Weight (kg)	Age Specific Intake (g dw/day)	Exposure Duration Averaging Factor	Time Weighted Average Daily Intake (g dw/day)
13-30	0.03	70	2.1	(18 yrs/24 yrs)	1.575
7-12	0.05	70	3.5	(6 yrs/24 yrs)	0.875
1-6	0.07	15	1.05	(5 yrs/6 yrs)	0.875
0-1	0.26	15	3.9	(1 yr/6 yrs)	0.65

CONSUMPTION RATE:

6-30 yrs = (0.75 g dw/day + 0.875 g dw/day) = 2.45 g dw/day
0-6 yrs = (0.875 g dw/day + 0.65 g dw/day) = 1.52 g dw/day

a Source: Methodology for Assessing Health Risks Associated with Indirect Exposures to Combustor Emissions (USEPA 1990a).

Table E-6
CALCULATION OF CONSUMPTION RATE FOR HOMEGROWN VEGETABLES:
POTATOES

Age Group (years)	70-75th percentile Consumption Rate[a] (g dw/kg bw/day)	Body Weight (kg)	Age Specific Intake (g dw/day)	Exposure Duration Averaging Factor	Time Weighted Average Daily Intake (g dw/day)
13-30	0.285[b]	70	19.95	(18 yrs/24 yrs)	14.96
7-12	0.49	70	34.3	(6 yrs/24 yrs)	8.57
1-6	0.65	15	9.75	(5 yrs/6 yrs)	8.12
0-1	0.25	15	3.75	(1 yrs/6 yrs)	0.625

CONSUMPTION RATE:

6-30 yrs = (14.96 g dw/day + 8.57 g dw/day) = 23.5 g dw/day
0-6 yrs = (8.12 g dw/day + 0.625 g dw/day) = 8.7 g dw/day

a Source: Methodology for Assessing Health Risks Associated with Indirect Exposures to Combustor Emissions (USEPA 1990a).
b Average for males and females.

Table E-7
CALCULATION OF CONSUMPTION RATE FOR HOMEGROWN VEGETABLES:
LEGUMES

Age Group (years)	70-75th percentile Consumption Rate[a] (g dw/kg bw/day)	Body Weight (kg)	Age Specific Intake (g dw/day)	Exposure Duration Averaging Factor	Time Weighted Average Daily Intake (g dw/day)
13-30	0.53[b]	70	37.1	(18 yrs/24 yrs)	27.8
7-12	0.98	70	68.6	(6 yrs/24 yrs)	17.15
1-6	1.3	15	19.5	(5 yrs/6 yrs)	16.25
0-1	2.4	15	36.0	(1 yrs/6 yrs)	6.0

CONSUMPTION RATE:

6-30 yrs = (27.8 g dw/day + 17.15 g dw/day) = 45 g dw/day
0-6 yrs = (16.25 g dw/day + 6.0 g dw/day) = 22.25 g dw/day

a Source: Methodology for Assessing Health Risks Associated with Indirect Exposures to Combustor Emissions (USEPA 1990a).
b Average for males and females.

The percent of vegetables consumed that are grown in home gardens (diet fractions home-grown) for five vegetable classes are summarized in Table E-8. These values were also derived from the 1977-78 NFCS and summarized in "Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions" (USEPA 1990a). The values were determined from survey data by subtracting the reported quantities of bought food from the reported quantities of food from all sources, and this difference was divided by the quantities of food from all sources to determine the percentage "produced at home". The values were determined for central city, suburban and rural areas. For this assessment suburban values were selected as the most representative of the Ruston/North Tacoma study area.

Table E-8
PERCENTAGE OF VARIOUS PLANTS GROWN IN HOME GARDENS[a]

Vegetable Class	Vegetable	Percent Grown At Home	Average Percent by Vegetable Class[b]
Fruity	cucumber	39	39
	pumpkin, squash	45	
	peppers	26.3	
	tomatoes	46.6	
Leafy	lettuce	4.44	11
	spinach	16.7	
Root	carrots	14.3	19
	onions	8.00	
	turnips	33.3	
Potatoes	white potatoes	6.54	11
	sweet potatoes	15.4	
Legumes	beans, lima	66.7	62
	beans, succulent	57.6	
	green peas	62.5	

a Source: Methodology for Assessing Health Risks Associated With Indirect Exposures to Combustor Emissions (USEPA 1990a).

b This value is used as the home grown garden fraction to estimate exposures in Section 4.